US005813972A

United States Patent [19]

Nazarian et al.

[11] **Patent Number: 5,813,972**

[45] **Date of Patent: Sep. 29, 1998**

[54] **MEDICAL PERFUSION SYSTEM WITH DATA COMMUNICATIONS NETWORK**

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[73] Assignee: **Minnesota Mining and Manufacturing Company**, St. Paul, Minn.

[21] Appl. No.: **723,504**

[22] Filed: **Sep. 30, 1996**

[51] **Int. Cl.**[6] **A61M 1/00**

[52] **U.S. Cl.** **600/17**

[58] **Field of Search** 600/17, 16, 18; 607/2, 3

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Primary Examiner—William E. Kamm

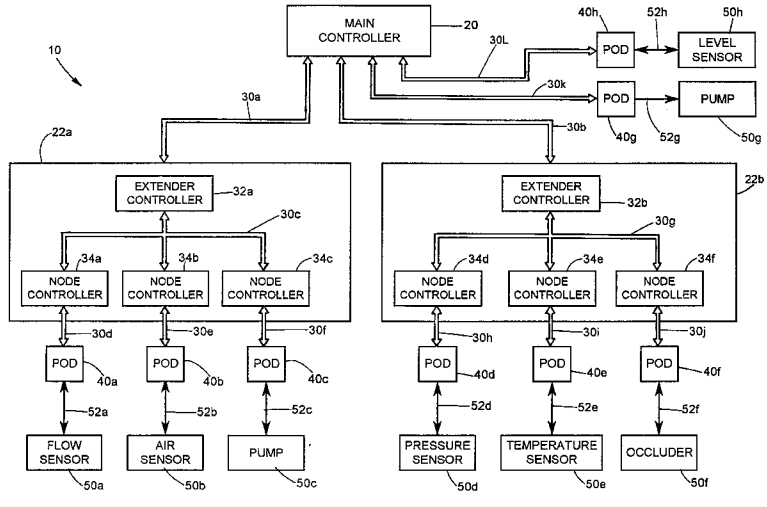
Assistant Examiner—Kennedy J. Schaetzle

Attorney, Agent, or Firm—Gary L. Griswold; Stephen W. Bauer; Martin J. Hirsch

[57] **ABSTRACT**

A medical perfusion system for use in connection with the medical treatment of a patient is provided with a first type of perfusion device in the form of a blood pump adapted to pump blood through a fluid conduit connected to the patient, a second type of perfusion device in the form of a sensor adapted to sense a condition relating to the pumping of blood through the fluid conduit and to generate a sensing signal relating to the condition, and a data communications network for operatively interconnecting the perfusion devices. The perfusion system also includes means for transmitting messages in the form of digital data packets among the perfusion devices over the data communications network and a controller operatively coupled to the perfusion devices via the data communications network, the controller having an input device for accepting pump control commands relating to the blood pump from an operator.

15 Claims, 15 Drawing Sheets



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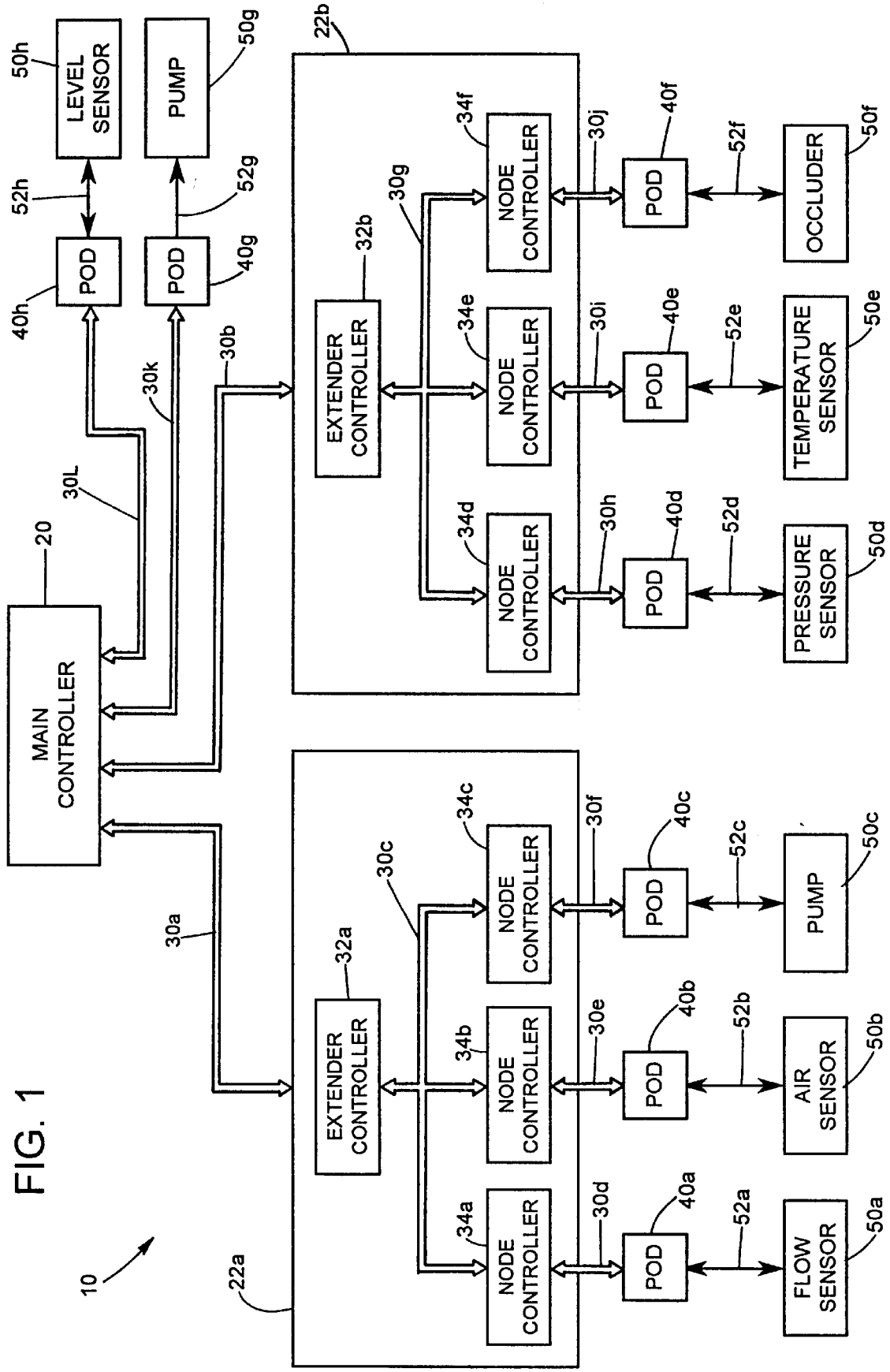

MAIN CONTROLLER
20
10
30L
30a
30b
30c
30d
30e
30f
30g
30h
30i
30j
30k
22a
22b
EXTENDER CONTROLLER
32a
32b
NODE CONTROLLER
34a
34b
34c
34d
34e
34f
POD
40a
40b
40c
40d
40e
40f
40g
40h
52a
52b
52c
52d
52e
52f
52g
52h
FLOW SENSOR
50a
AIR SENSOR
50b
PUMP
50c
PRESSURE SENSOR
50d
TEMPERATURE SENSOR
50e
OCCLUDER
50f
PUMP
50g
LEVEL SENSOR
50h

FIG. 1

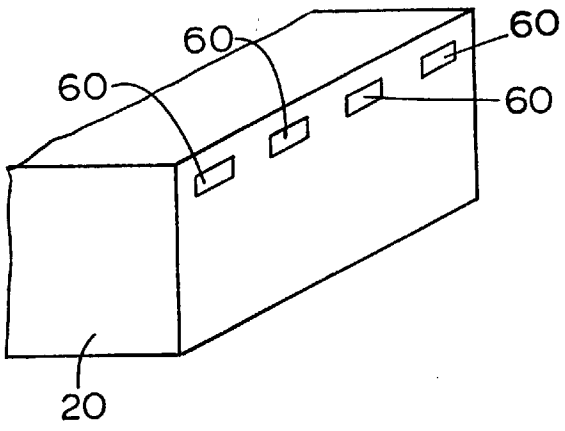


FIG. 2

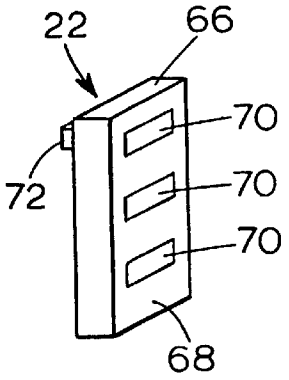


FIG.3

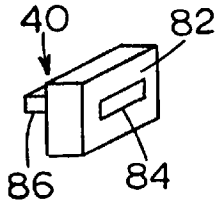


FIG. 4

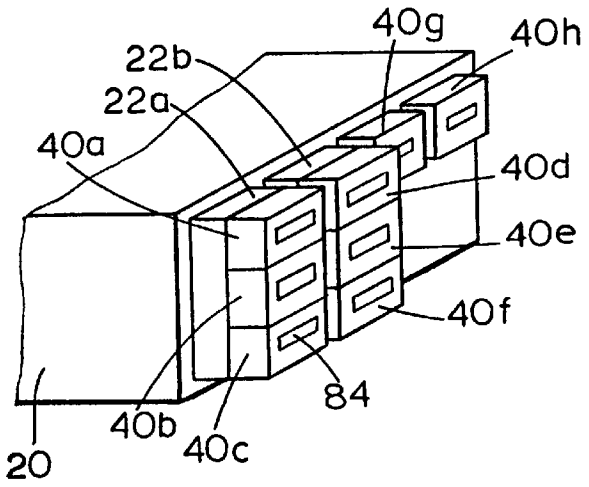


FIG. 8

FIG. 5

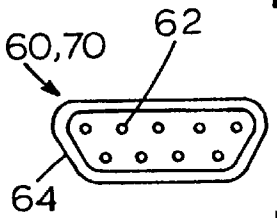


FIG. 6

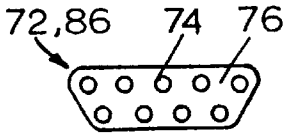
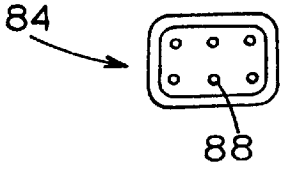


FIG. 7



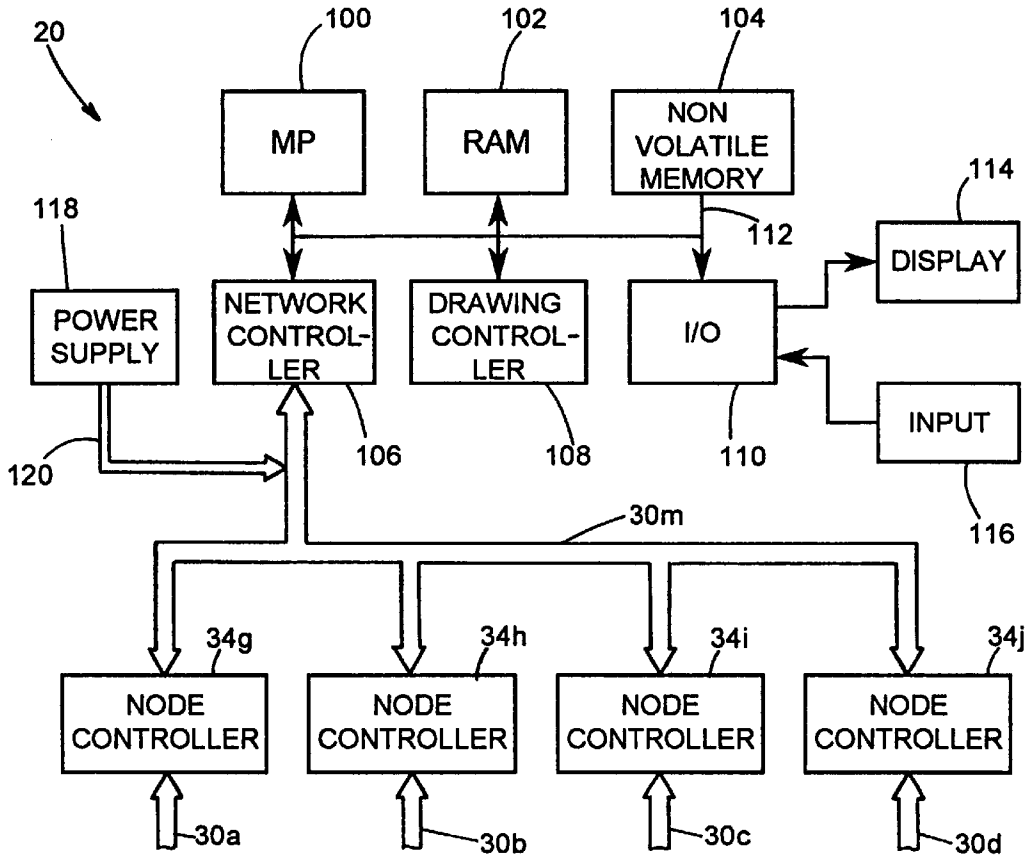

20
100
102
104
MP
RAM
NON VOLATILE MEMORY
114
118
112
DISPLAY
POWER SUPPLY
NETWORK CONTROL-LER
DRAWING CONTROL-LER
I/O
INPUT
120
106
108
110
116
30m
34g
34h
34i
34j
NODE CONTROLLER
NODE CONTROLLER
NODE CONTROLLER
NODE CONTROLLER
30a
30b
30c
30d

FIG. 9

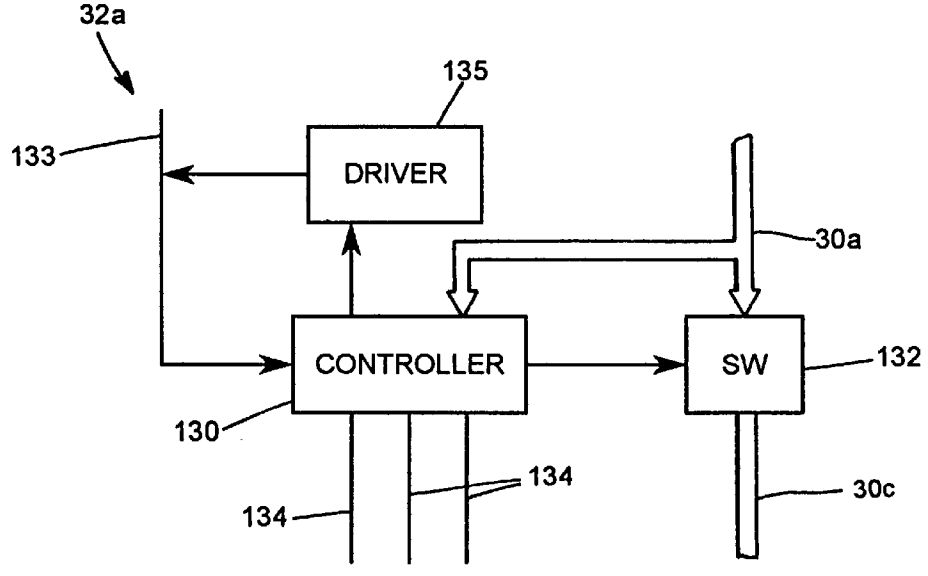

32a
135
133
DRIVER
30a
CONTROLLER
SW
132
130
134
134
30c

FIG. 10

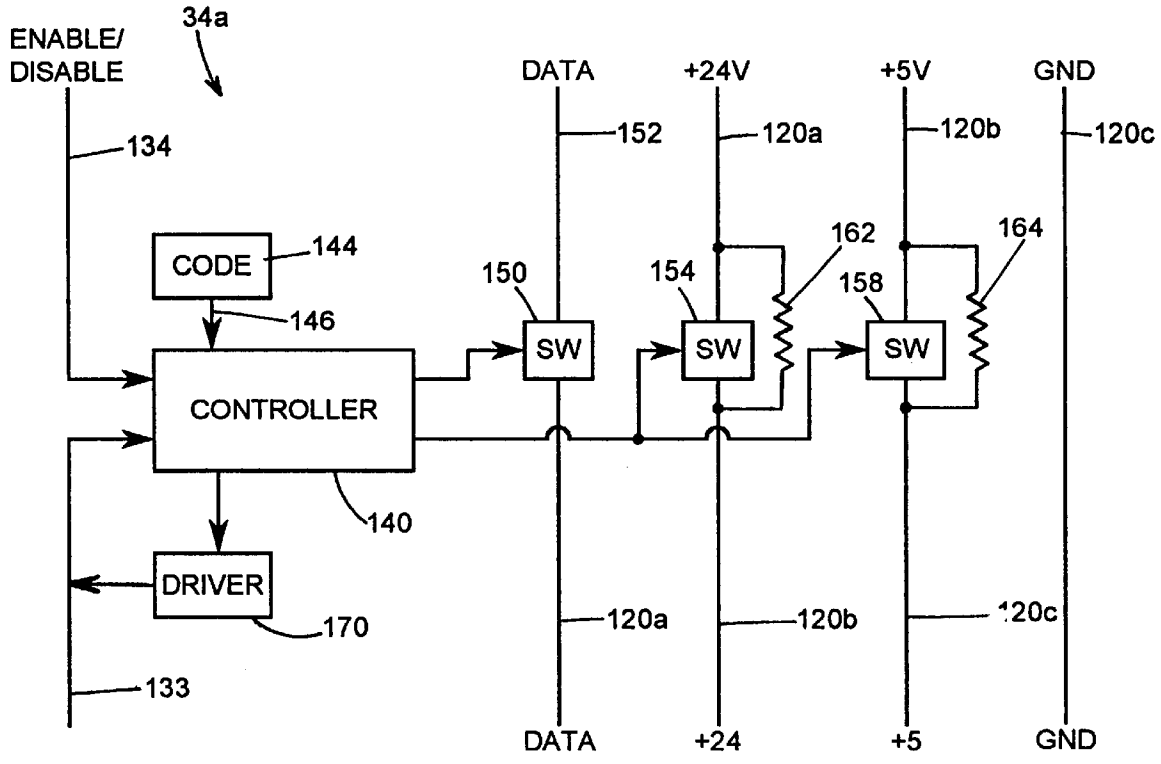

ENABLE/
DISABLE
34a
134
DATA
+24V
+5V
GND
152
120a
120b
120c
CODE
144
146
150
154
158
162
164
SW
SW
SW
CONTROLLER
140
DRIVER
170
133
120a
120b
120c
DATA
+24
+5
GND

FIG. 11

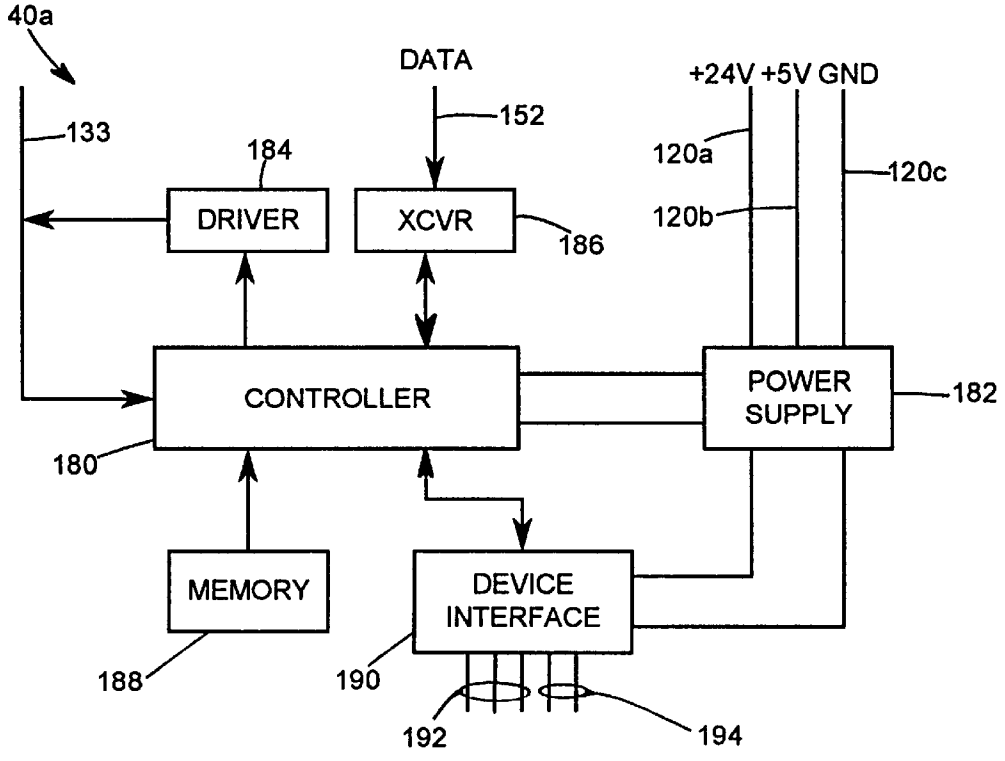

40a
133
DATA
152
+24V +5V GND
120a
120b
120c
184
DRIVER
XCVR
186
CONTROLLER
POWER
SUPPLY
182
180
MEMORY
DEVICE
INTERFACE
188
190
192
194

FIG. 12

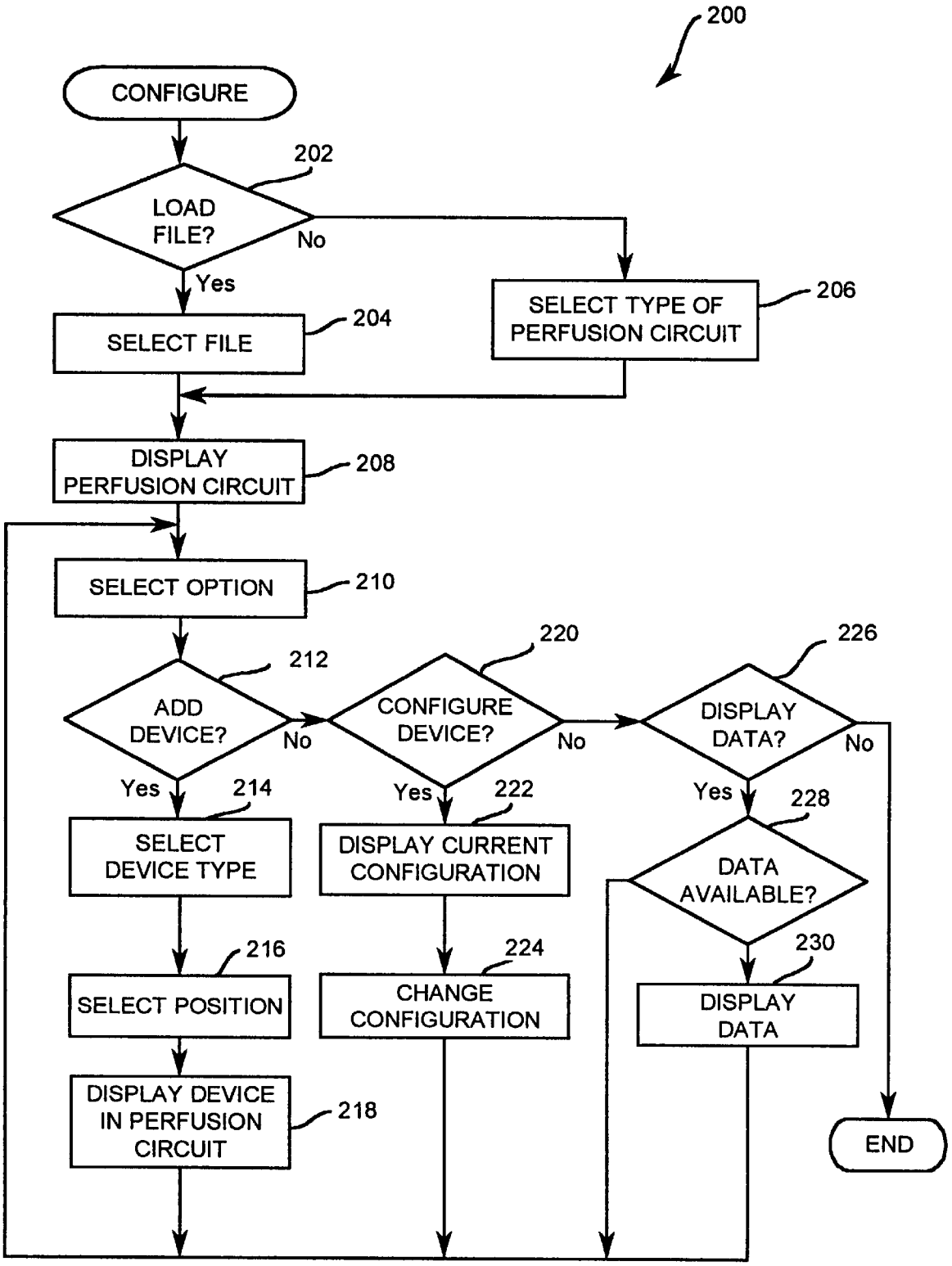

200
CONFIGURE
202
LOAD FILE?
No
Yes
SELECT FILE
204
SELECT TYPE OF PERFUSION CIRCUIT
206
DISPLAY PERFUSION CIRCUIT
208
SELECT OPTION
210
212
ADD DEVICE?
No
Yes
214
SELECT DEVICE TYPE
216
SELECT POSITION
DISPLAY DEVICE IN PERFUSION CIRCUIT
218
220
CONFIGURE DEVICE?
No
Yes
222
DISPLAY CURRENT CONFIGURATION
224
CHANGE CONFIGURATION
226
DISPLAY DATA?
No
Yes
228
DATA AVAILABLE?
230
DISPLAY DATA
END

FIG. 13A

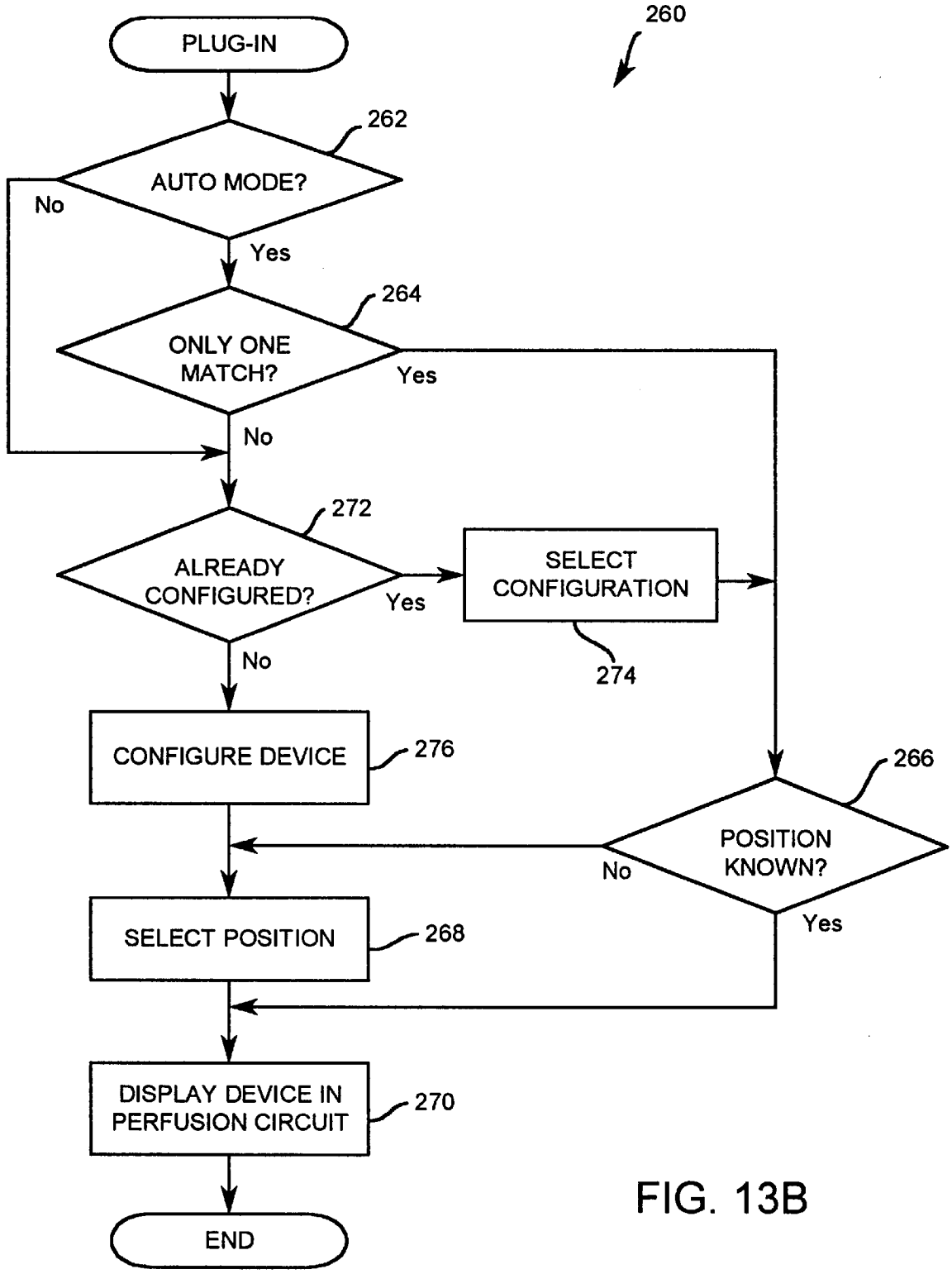

260
PLUG-IN
262
AUTO MODE?
No
Yes
264
ONLY ONE MATCH?
Yes
No
272
ALREADY CONFIGURED?
Yes
SELECT CONFIGURATION
274
No
CONFIGURE DEVICE
276
266
POSITION KNOWN?
No
Yes
SELECT POSITION
268
DISPLAY DEVICE IN PERFUSION CIRCUIT
270
END

FIG. 13B

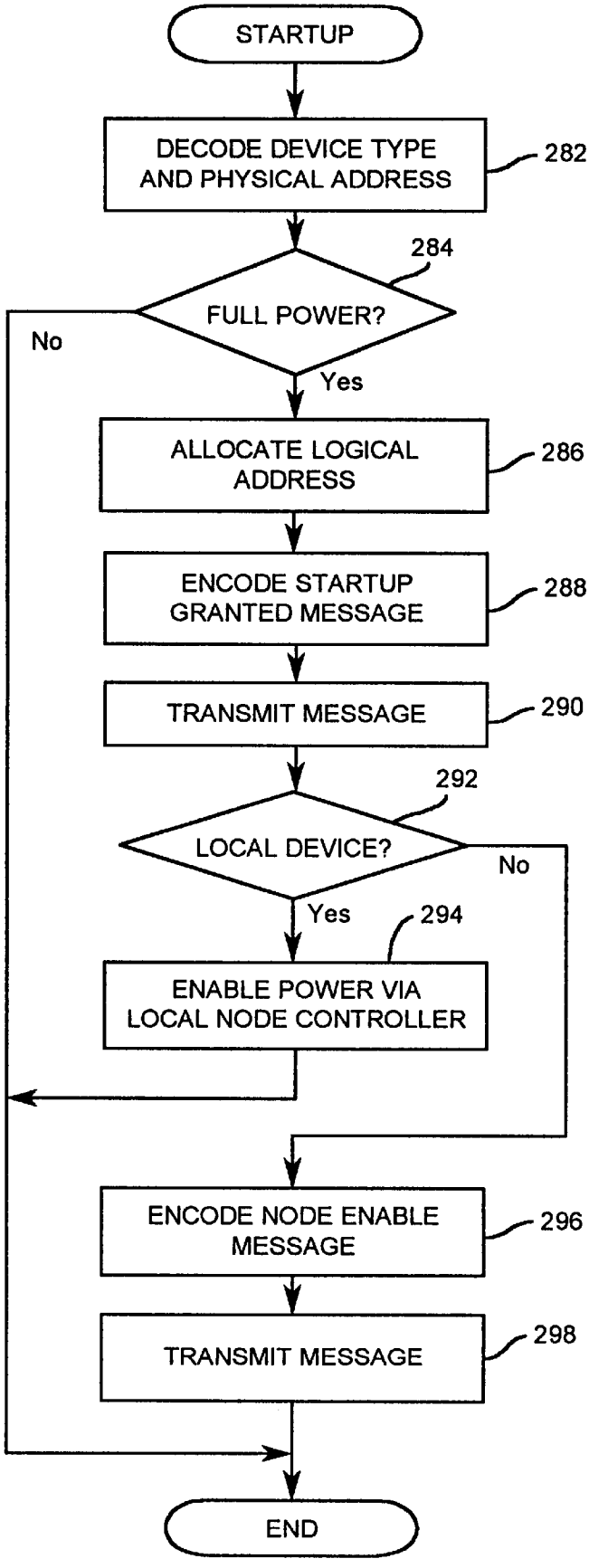

280
STARTUP
DECODE DEVICE TYPE AND PHYSICAL ADDRESS
282
284
FULL POWER?
No
Yes
ALLOCATE LOGICAL ADDRESS
286
ENCODE STARTUP GRANTED MESSAGE
288
TRANSMIT MESSAGE
290
292
LOCAL DEVICE?
No
Yes
294
ENABLE POWER VIA LOCAL NODE CONTROLLER
ENCODE NODE ENABLE MESSAGE
296
TRANSMIT MESSAGE
298
END

FIG. 13C

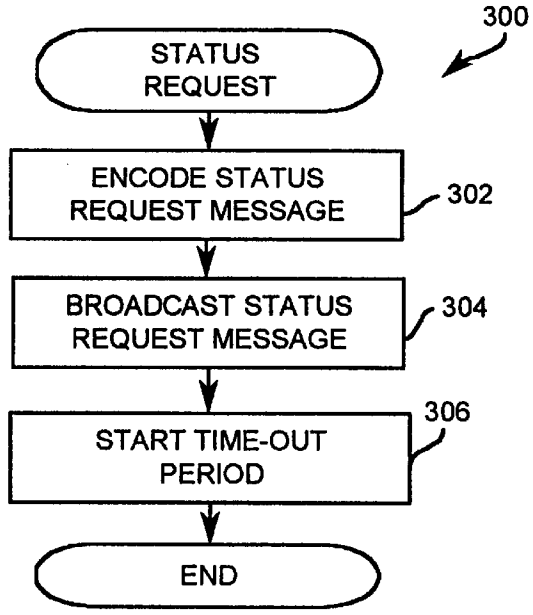


FIG. 13D

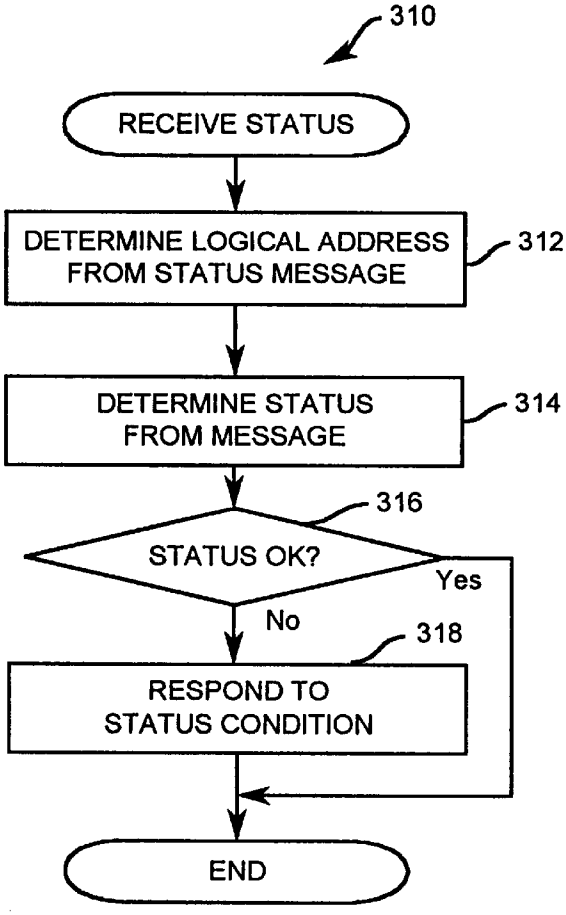


FIG. 13E

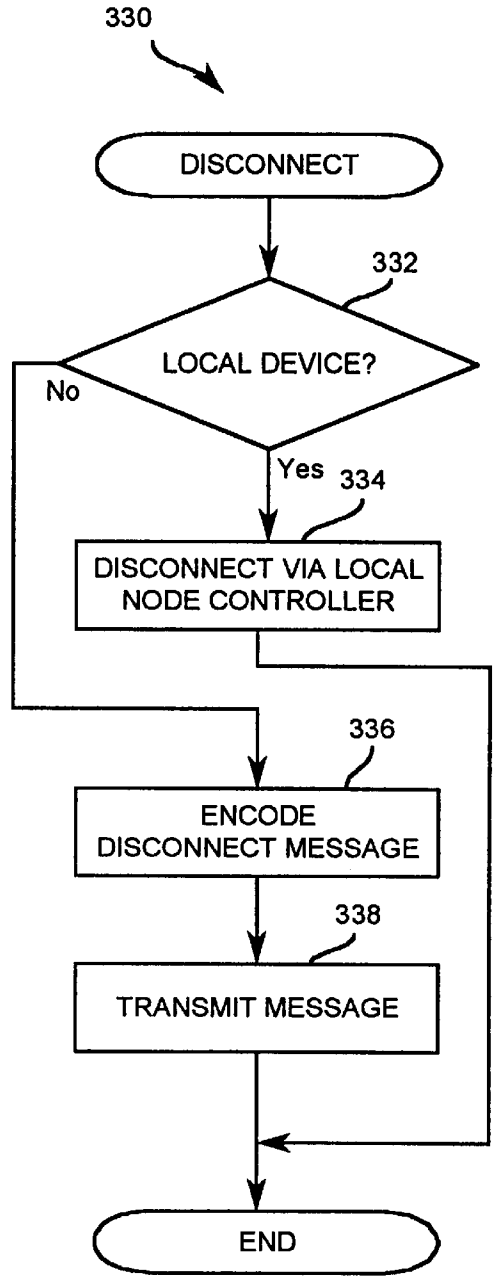


FIG. 13F

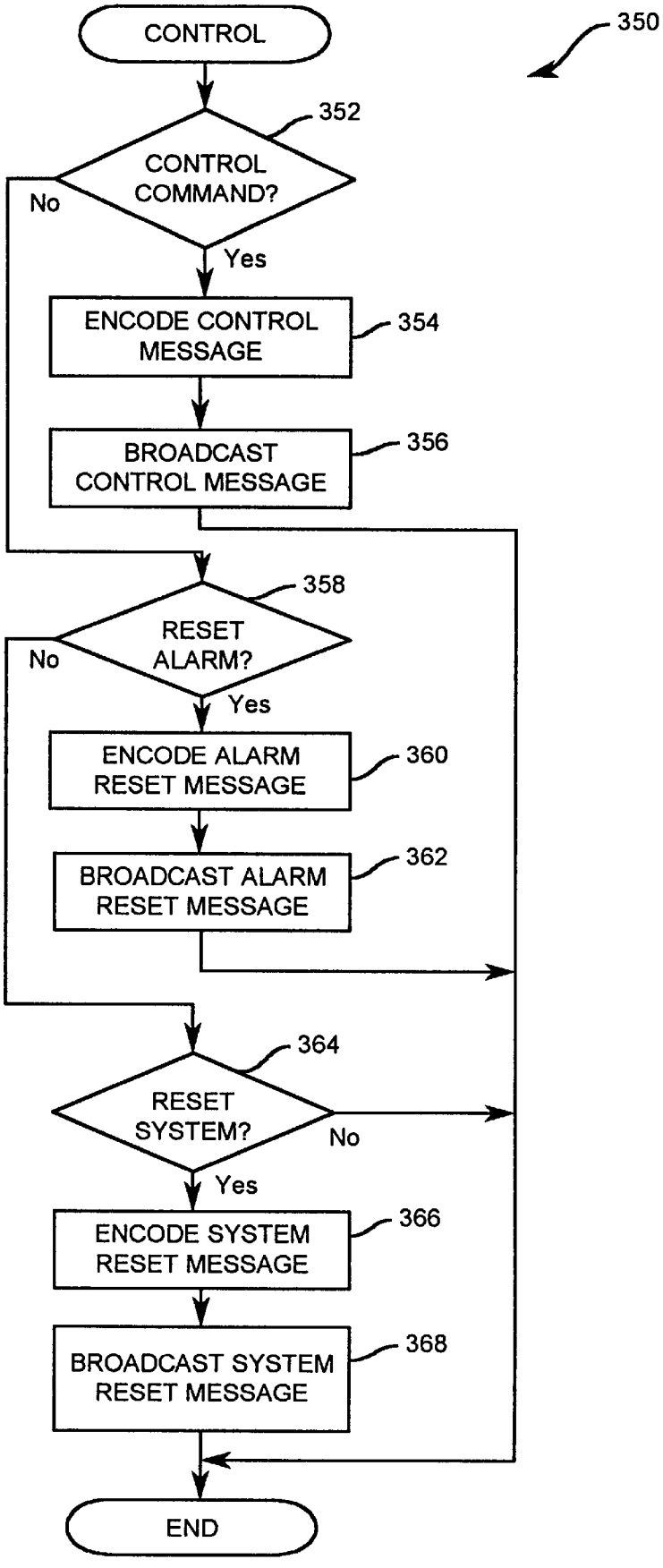

CONTROL
350
352
CONTROL COMMAND?
No
Yes
ENCODE CONTROL MESSAGE
354
BROADCAST CONTROL MESSAGE
356
358
RESET ALARM?
No
Yes
ENCODE ALARM RESET MESSAGE
360
BROADCAST ALARM RESET MESSAGE
362
364
RESET SYSTEM?
No
Yes
ENCODE SYSTEM RESET MESSAGE
366
BROADCAST SYSTEM RESET MESSAGE
368
END

FIG. 13G

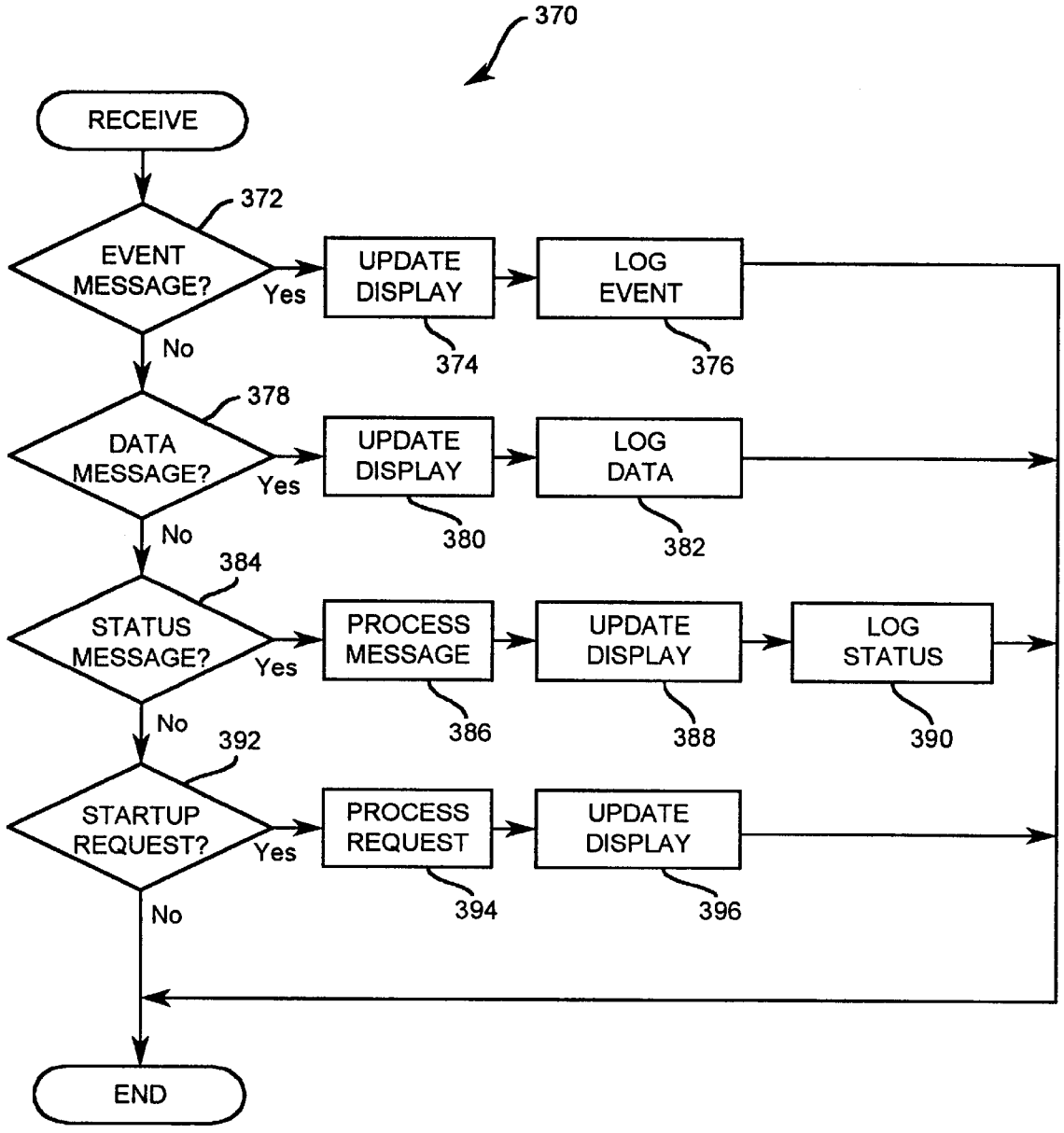

370
RECEIVE
372
EVENT MESSAGE?
Yes
UPDATE DISPLAY
LOG EVENT
374
376
No
378
DATA MESSAGE?
Yes
UPDATE DISPLAY
LOG DATA
380
382
No
384
STATUS MESSAGE?
Yes
PROCESS MESSAGE
UPDATE DISPLAY
LOG STATUS
386
388
390
No
392
STARTUP REQUEST?
Yes
PROCESS REQUEST
UPDATE DISPLAY
394
396
No
END

FIG. 13H

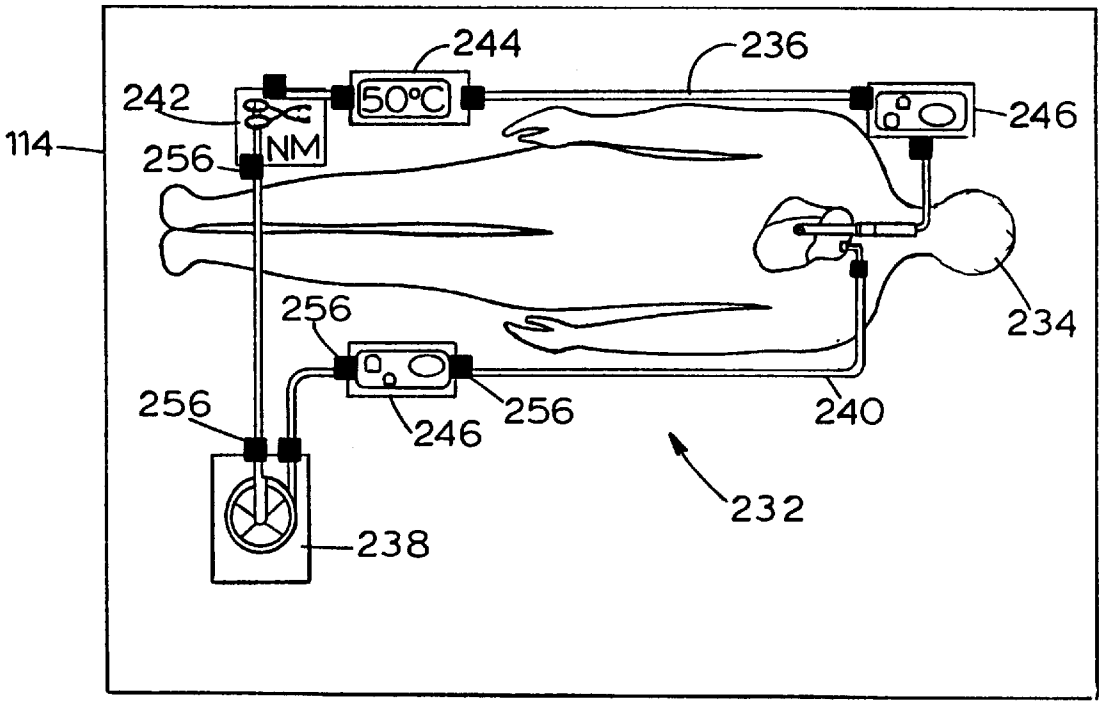


FIG. 14A

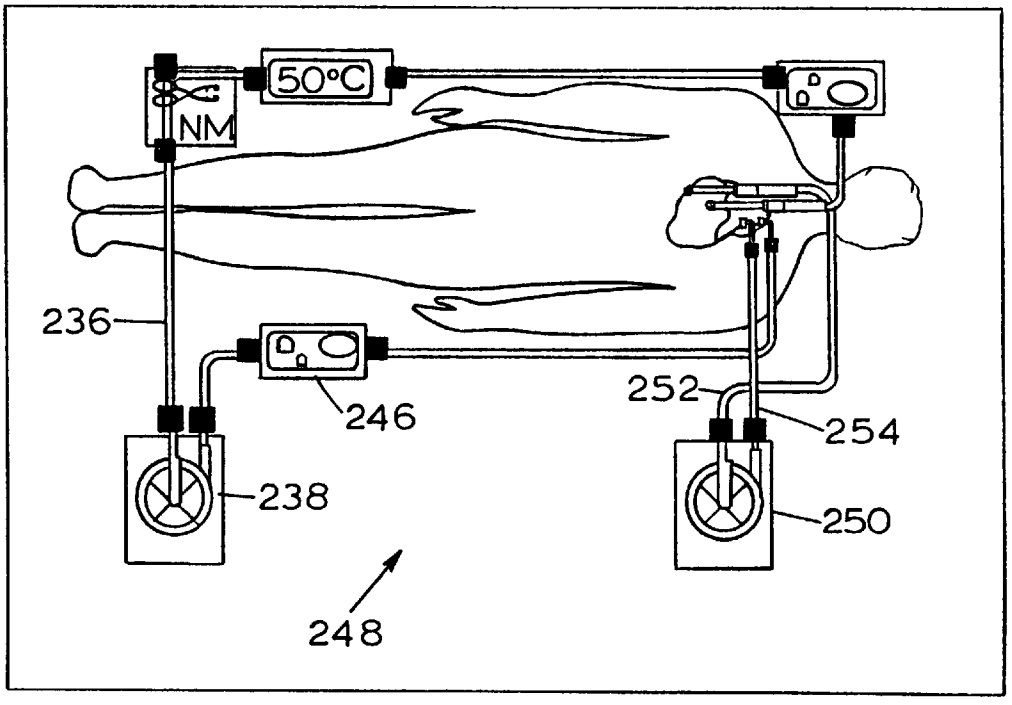


FIG. 14B

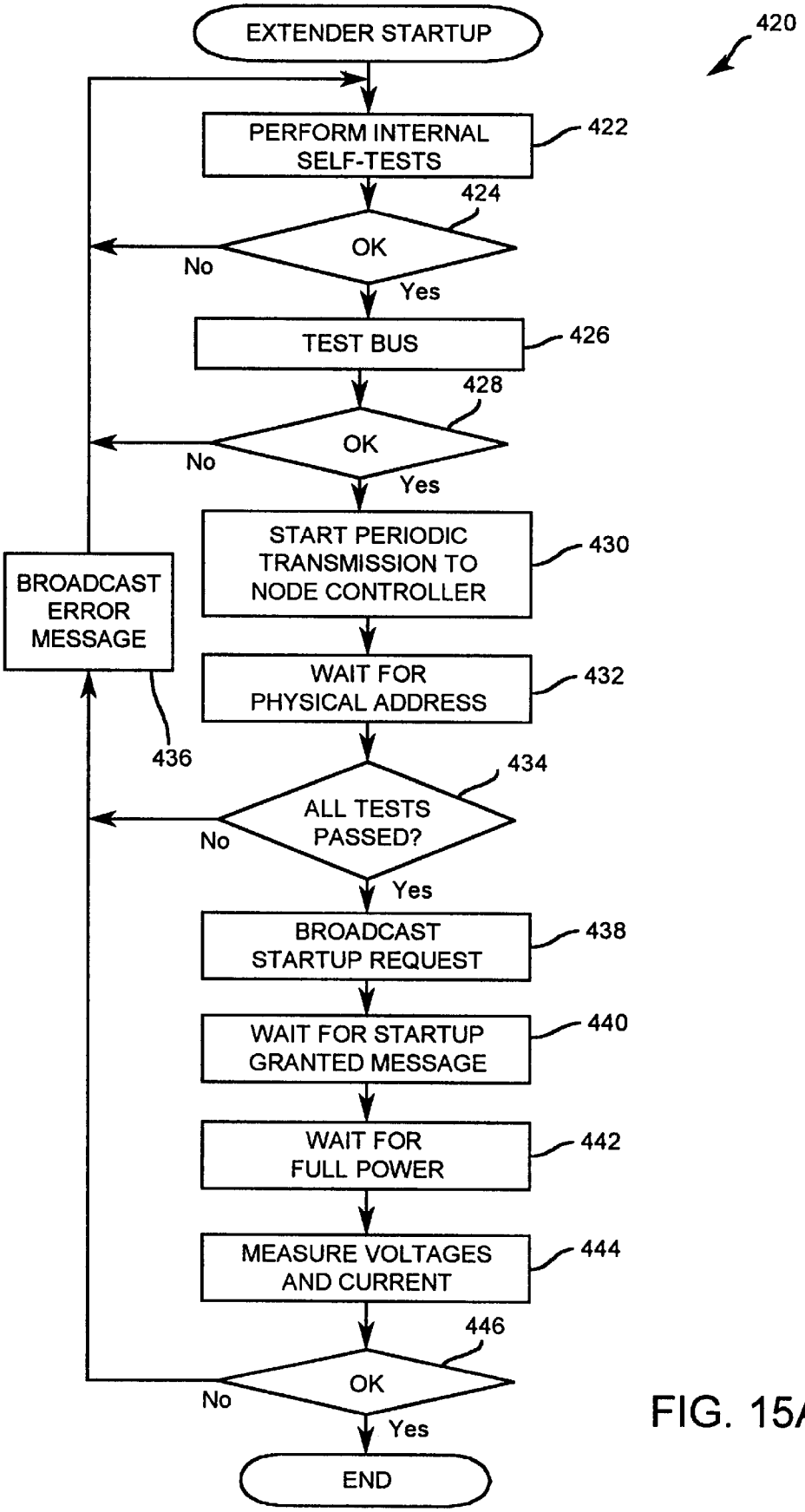

EXTENDER STARTUP
420
PERFORM INTERNAL SELF-TESTS
422
424
OK
No
Yes
TEST BUS
426
428
OK
No
Yes
START PERIODIC TRANSMISSION TO NODE CONTROLLER
430
BROADCAST ERROR MESSAGE
WAIT FOR PHYSICAL ADDRESS
432
436
434
ALL TESTS PASSED?
No
Yes
BROADCAST STARTUP REQUEST
438
WAIT FOR STARTUP GRANTED MESSAGE
440
WAIT FOR FULL POWER
442
MEASURE VOLTAGES AND CURRENT
444
446
OK
No
Yes
END

FIG. 15A

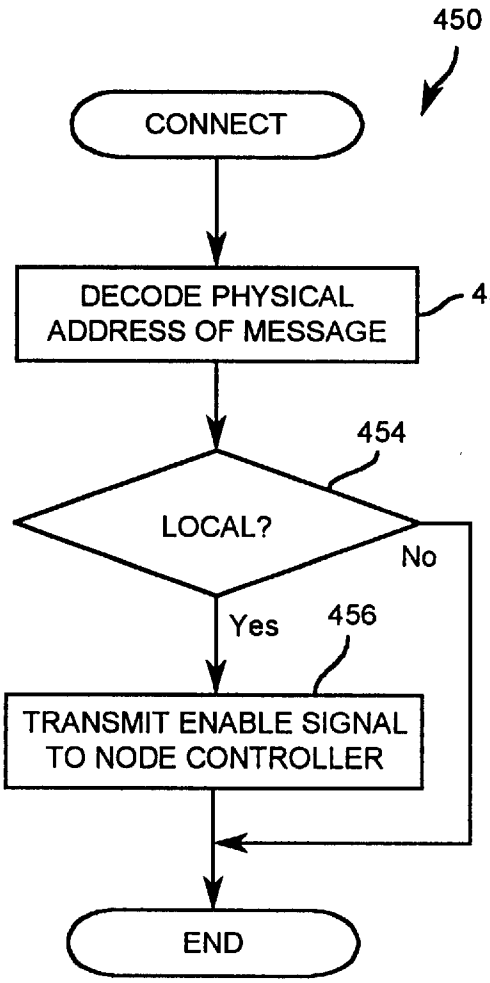


FIG. 15B

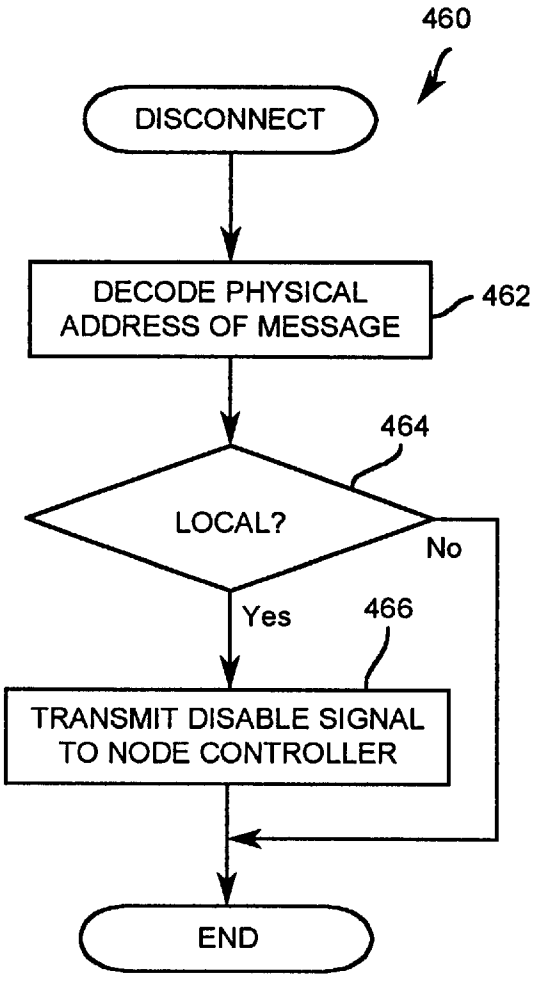


FIG. 15C

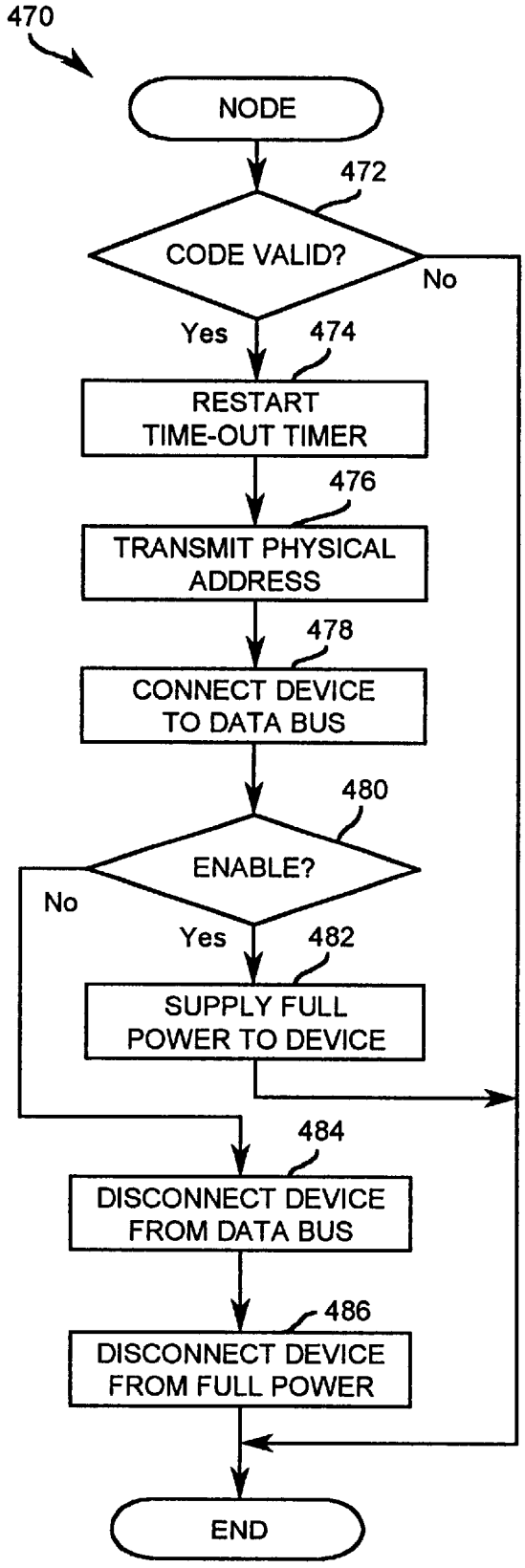


FIG. 16A

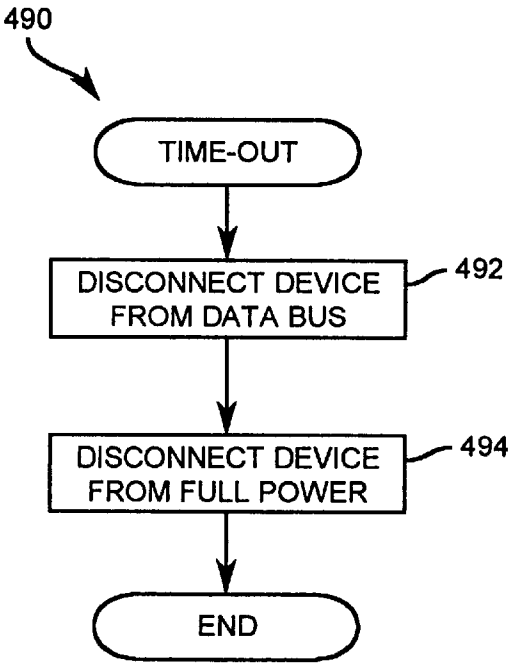


FIG. 16B

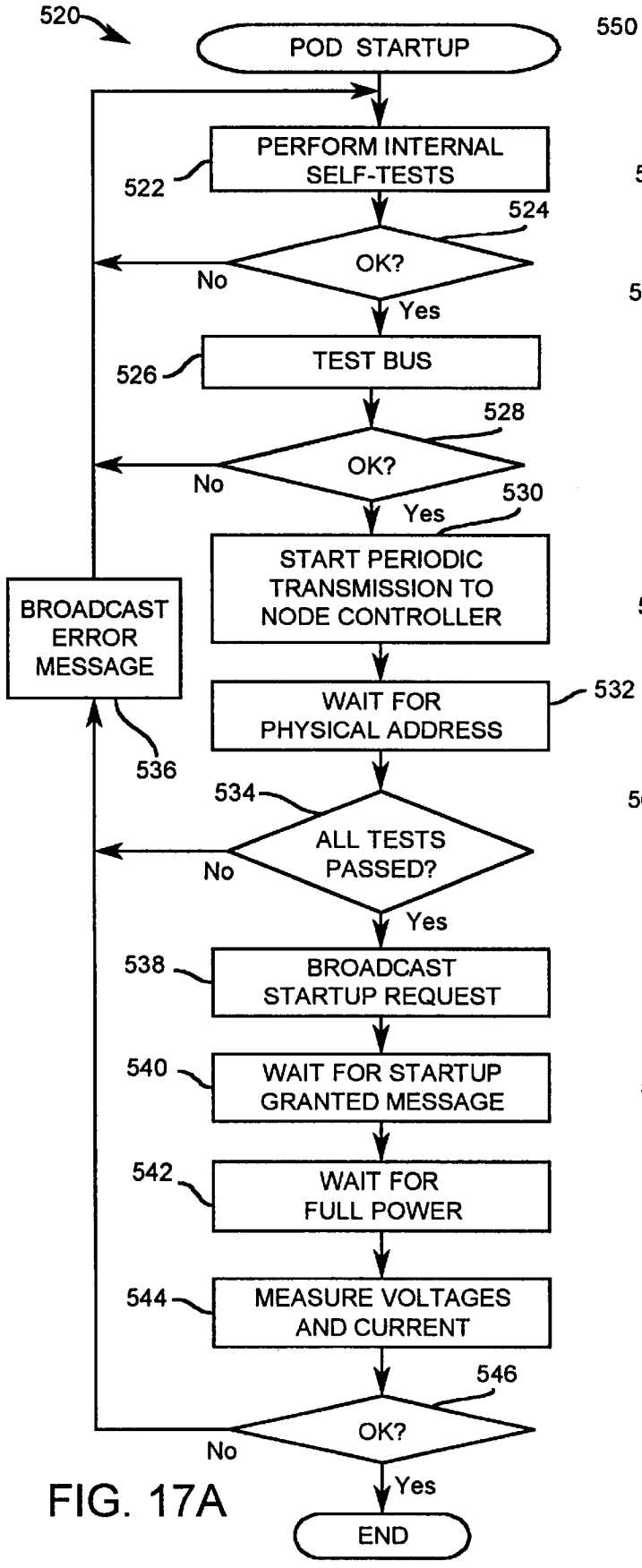


FIG. 17A

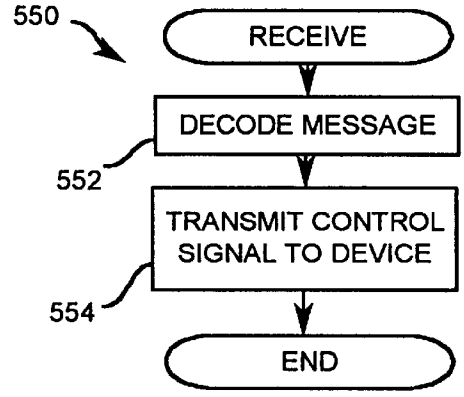


FIG. 17B

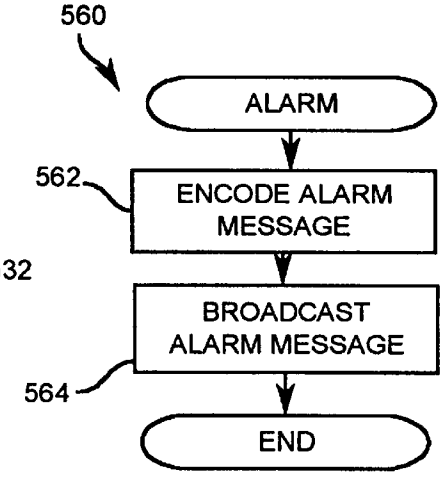


FIG. 17C

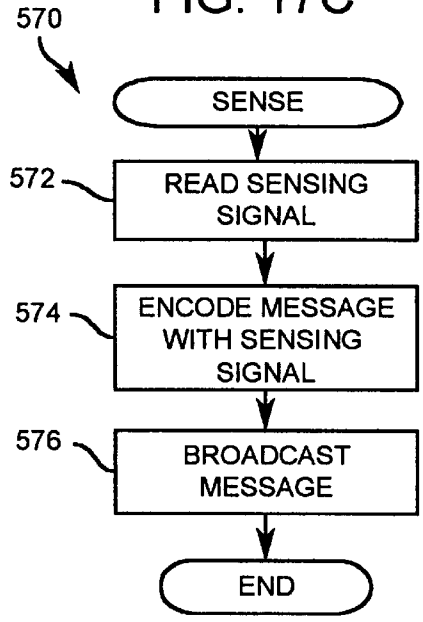


FIG. 17D

MEDICAL PERFUSION SYSTEM WITH DATA COMMUNICATIONS NETWORK

BACKGROUND OF THE INVENTION

The present invention is directed to a medical perfusion system adapted to handle the selective oxygenation, filtering and recirculation of blood in connection with various medical procedures.

A conventional perfusion system may be used to oxygenate, filter, and/or recirculate the blood of a patient during a medical procedure. Such a perfusion system may have a fluid conduit that removes blood from the patient during the medical procedure, a separate fluid conduit that returns blood to the patient, one or more blood pumps that pump blood through the conduits, and a plurality of sensing devices, such as flow sensors and/or level sensors associated with blood pumps. The perfusion system may also include air embolus sensors, temperature sensors, flow occluders, etc.

Typically, a perfusion system is provided with a configuration specifically designed to be used for a particular purpose. For example, one perfusion system may be specifically designed as a full-function heart/lung machine, while another perfusion system may be specifically designed as a ventricular-assist system. Although it may be possible to convert a perfusion system designed for one purpose to a perfusion system usable for a different purpose, such reconfiguration is generally difficult and/or time-consuming.

SUMMARY OF THE INVENTION

The invention is directed to a medical perfusion system for use in connection with the medical treatment of a patient. The perfusion system includes a first type of perfusion device in the form of a blood pump adapted to pump blood through a fluid conduit connected to the patient, a second type of perfusion device in the form of a sensor adapted to sense a condition relating to the pumping of blood through the fluid conduit and to generate a sensing signal relating to the condition, and a data communications network for operatively interconnecting the perfusion devices. The perfusion system also includes means for transmitting messages in the form of digital data packets among the perfusion devices over the data communications network and a controller operatively coupled to the perfusion devices via the data communications network, the controller having an input device for accepting pump control commands from an operator.

The data communications network may be provided with a plurality of network connectors, each of which has an identical connector configuration, and the perfusion system may include at least two adapter pods, each of which has a common connector adapted to be coupled to one of the network connectors and a device connector adapted to be coupled to one of the perfusion devices. The message transmitting means may include means for generating a message containing a control command for the pump and means for generating a message containing data relating to the sensed condition.

The controller may include a plurality of network connectors, and the data communications network may include a network extender having a network connector adapted to be coupled to one of the network connectors of the controller, a plurality of extender connectors adapted to be connected to the common connectors of the adapter pods, and a data bus electrically interconnecting the network connector of the network extender with each of the extender connectors.

In another aspect, the invention is directed to an adapter pod for use in a medical perfusion system having a data communications network with a plurality of connection points each having a substantially identical network connector. The adapter pod includes a common connector adapted to be connected to one of the network connectors, a device connector adapted to be connected to a perfusion device, and means for generating a message in the form of a digital data packet.

These and other features of the invention will be apparent to those of ordinary skill in the art in view of the detailed description of the preferred embodiments, which is made with reference to the drawings, a brief description of which is provided below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a preferred embodiment of a perfusion system in accordance with the invention;

FIG. **2** is a perspective view of the main controller shown schematically in FIG. **1**;

FIG. **3** is a perspective view of one of the network extenders shown schematically in FIG. **1**;

FIG. **4** is a perspective view of one of the adapter pods shown schematically in FIG. **1**;

FIGS. **5–7** illustrate a number of connector configurations;

FIG. **8** is a perspective view of the main controller shown schematically in FIG. **1** with two network extenders and eight adapter pods plugged therein;

FIG. **9** is a block diagram of the main controller shown schematically in FIG. **1**;

FIG. **10** is a block diagram of one of the extender controllers shown schematically in FIG. **1**;

FIG. **11** is a block diagram of one of the node controllers shown schematically in FIG. **1**;

FIG. **12** is a block diagram of one of the adapter pods shown schematically in FIG. **1**;

FIGS. **13A–13H** are flowcharts illustrating the operation of the main controller shown in FIG. **1**;

FIGS. **14A–14B** are exemplary illustrations of a pair of perfusion circuit images generated on the display device of FIG. **9** during operation of the perfusion system;

FIGS. **15A–15C** are flowcharts illustrating the operation of the extender controllers shown in FIG. **1**;

FIGS. **16A–16B** are flowcharts illustrating the operation of the node controllers shown in FIG. **1**; and

FIGS. **17A–17D** are flowcharts illustrating the operation of the adapter pods shown in FIG. **1**.

DETAILED OF THE PREFERRED EMBODIMENTS

FIG. **1** illustrates a preferred embodiment of a medical perfusion system **10** in accordance with the invention. The perfusion system **10** is adapted to handle the selective oxygenation, filtering and recirculation of blood in connection with a number of different medical procedures. The perfusion system **10** may be placed in a number of different configurations, each of which corresponds to a different medical procedure. For example, the perfusion system **10** may be configured as a full-function heart/lung machine, a ventricular assist system, or a single-pump system that can be used for various purposes, such as to perform blood aspiration or myocardial protection during surgery.

Referring to FIG. **1**, the main controller **20** is connected to a network extender **22***a* via a data/power bus **30***a* and to a network extender **22***b* via a data/power bus **30***b*. The network extender **22***a* includes an extender controller **32***a* connected to three node controllers **34***a*, **34***b*, **34***c* via a data/power bus **30***c*. The node controller **34***a* is connected via a data/power bus **30***d* to an adapter pod **40***a*, which is in turn connected to a perfusion device **50** in the form of a flow sensor **50***a* via a bidirectional data/power line **52***a*. The node controller **34***b* is connected via a data/power bus **30***e* to an adapter pod **40***b*, which is connected to an air embolus sensor **50***b* via a bidirectional line **52***b*. The node controller **34***c* is connected via a data/power bus **30***f* to an adapter pod **40***c*, which is connected to a blood pump **50***c* via a bidirectional line **52***c*.

The network extender **22***b* includes an extender controller **32***b* connected to three node controllers **34***d*, **34***e*, **34***f* via a data/power bus **30***g*. The node controller **34***d* is connected via a data/power bus **30***h* to an adapter pod **40***d*, which is connected to a pressure sensor **50***d* via a bidirectional line **52***d*. The node controller **34***e* is connected via a data/power bus **30***i* to an adapter pod **40***e*, which is connected to a temperature sensor **50***e* via a bidirectional line **52***e*. The node controller **34***f* is connected via a data/power bus **30***j* to an adapter pod **40***f*, which is connected to a flow occluder **50***f* via a bidirectional line **52***f*.

The main controller **20** is operatively coupled to a blood pump **50***g* via a bidirectional line **52***g* connected to an adapter pod **40***g*. The pod **40***g* is connected to the main controller **20** via a data/power bus **30***k*. The main controller **20** is operatively coupled to a level sensor **50***h* via a bidirectional line **52***h* connected to an adapter pod **40***h*, which is connected to the main controller **20** via a data/power bus **301**.

As used herein, the term "perfusion device" is a device designed to be used in a medical perfusion system, including but not limited to a blood pump such as a centrifugal or roller pump, a flow sensor, a pressure sensor, a temperature sensor, a level sensor, an air embolus sensor or an occluder.

Mechanical Structure of Network Components

FIG. **2** is a perspective view of a portion of one mechanical embodiment of the main controller **20**. Referring to FIG. **2**, the main controller **20** has four network connectors **60**, which are shown schematically. Each of the network connectors **60** is identical and has the same connector configuration. FIG. **5** illustrates the structure of the connectors **60**. As shown in FIG. **5**, each connector **60** may be, for example, a standard personal computer connector having nine conductive pins **62** partially surrounded by an asymmetrical metal housing **64**.

FIG. **3** is a perspective view of one embodiment of the network extenders **22** shown schematically in FIG. **1**. Each network extender **22** has a hexahedral housing **66** with one side **68** on which three connectors **70** are disposed and an opposite side on which a connector **72** is disposed. Each connector **70** is identical to the connectors **60** and has the structure shown in FIG. **5**. The connector **72**, which is shown in FIG. **6**, has nine pin receptacles **74** formed in an asymmetrical housing **76** composed of an insulating material such as plastic. The pin receptacles **74** are located to correspond to the positions of the nine pins **62** of the connector **60**. Consequently, the connector **72** has the same connector configuration as the connector **60** and thus can be plugged into the connector **60**.

FIG. **4** is a perspective view of the adapter pods **40** shown schematically in FIG. **1**. Referring to FIG. **4**, each adapter pod **40** has a hexahedral housing with one side **82** on which a connector **84** is disposed and an opposite side on which a connector **86** is disposed. The connector **86** is identical to the connectors **72** described above (and shown in FIG. **6**).

The connector **84** is adapted to be connected to a device connector (not shown) that is associated with one of the perfusion devices **50** described above. The connector **84** has a different connector configuration than the connectors **60**, **70**, **72**, **86**. One example of the structure of the connector **84** is shown in FIG. **7** to include six conductive pins **88**. Since each of the adapter pods **40** is adapted to be connected to a different type of perfusion device **50** (the pumps **50***c*, **50***g* may be different types of pumps, such as a roller pump or a centrifugal pump), the connector **84** disposed on each of the adapter pods **40** may have a different connector configuration.

Since the connectors **60** of the main controller **20** and the connectors **70** of the network extenders **22** have the same connector configuration as the connector **86** of the adapter pods **40**, it should be noted that any of the adapter pods **40** may be plugged into any of the connectors **60**, **70**. As a result, any combination of perfusion devices **50** may be connected to the main controller **20**.

FIG. **8** illustrates the main controller **20** having the network extenders **22** and the adapter pods **40** connected to it. Each of the adapter pods **40** of FIG. **8** would be connected to a respective one of the perfusion devices **50** shown in FIG. **1** via a respective connector (not shown) attached to the perfusion device **50** by a cable.

Although the form of the network extenders **22** shown in FIGS. **3** and **8** makes the resulting control unit compact, network extenders having different structures could be used. For example, instead of having the connector **72** fixed on the housing **66**, the connector **72** could be connected to the housing **66** via a cable. Alternatively, the housing **66** could be eliminated, and the connectors **70**, **72** could be interconnected via cables.

Electronics

FIG. **9** is a block diagram of the main controller **20** shown schematically in FIG. **1**. Referring to FIG. **9**, the main controller **20** has a microprocessor (MP) **100**, a random-access memory (RAM) **102**, a nonvolatile memory **104** such as a hard disk or a flash RAM, a network controller **106**, a drawing controller **108**, and an input/output (I/O) circuit **110**, all of which are interconnected by an address/data bus **112**. The I/O circuit **110** is connected to a display device **114**, such as a CRT or a flat-panel display, and an input device **116**, such as a keyboard or electronic mouse or a touch screen on the display device **114**.

The main controller **20** also includes a power supply circuit **118** that is connected to an outside source of AC power and which includes an internal transformer (not shown) that generates +5 volt and +24 volt DC power on a pair of electrical power lines relative to a ground line, which lines are schematically designated **120** in FIG. **9**. The electrical power and ground lines **120** are provided to each of four node controllers **34***g*–**34***j* via a data/power bus **30***m* and to the other node controllers **34** via the other portions of the network bus **30**. The data/power bus **30***m* includes a number of data communication lines which are connected to the network controller **106**.

FIG. **10** is a block diagram of the extender controller **32***a* shown schematically in FIG. **1** (the design of the extender controllers **32***a*, **32***b* is the same). Referring to FIG. **10**, the extender controller **32***a* has a controller **130** and a switch

132, both of which are connected to the data/power bus **30***a*. The extender controller **32***a* is connected to its parent node controller **34***g* via a bidirectional signal line **133**. As used herein, a "parent" device is a connected device that is closer to the network controller **106** (FIG. **9**) of the main controller **20**. The node controller **34***g* transmits a unique physical address to the extender controller **32***a* via the line **133**, and the extender controller **32***a* includes a driver circuit **135** which is used to periodically transmit a check-in code to the node controller **34***g* via the line **133**. The check-in code and the physical address may be the same binary code.

FIG. **11** illustrates a block diagram of the node controller **34***a* shown schematically in FIG. **1** (the design of all the node controllers **34** is the same). Referring to FIG. **11**, the node controller **34***a* has a controller **140** which receives an enable signal or a disable signal from the extender controller **32***a* via one of the lines **134** and a periodic check-in code from the adapter pod **40***a* via the line **133**. The controller **140** is connected to a code generator **144** via a multi-signal line **146**. The code generator **144** generates a predetermined multi-bit binary code that uniquely specifies the physical address of the node controller **34***a*. The code generator **144** may be, for example, a number of printed metal circuit lines, one line for each bit of the code, each line being selectively connected either to +5 volts (logic "1") or to ground (logic "0").

The controller **140** selectively operates a switch **150** that either connects or disconnects a data bus **152**, which may be composed of two individual data lines, that is part of the data/power buses **30***c*, **30***d* (and the other buses **30** that make up the network). When the switch **150** is open, the data buses **30***c*, **30***d* are disconnected, and when the switch **150** is closed, the buses **30***c*, **30***d* are connected to enable data communications between the adapter pod **40***a* and the other devices connected to the network **30**.

The controller **140** also operates a switch **154** that controls whether +24 volt DC power (relative to a ground line **120***c*) on a electrical power line **120***a* is supplied to the adapter pod **40***a* and a switch **158** that controls whether +5 volt DC power on an electrical power line **120***b* is supplied to the adapter pod **40***a*. The electrical power lines **120***a*, **120***b* are part of the data/power buses **30***c*, **30***d* and the other buses **30** that make up the network. A resistor **162** is connected in parallel with the switch **154**, and a resistor **164** is connected in parallel with the switch **158**. The resistors **162**, **164** act as current-limiting resistors which prevent large amounts of current from being drawn from the power lines **120***a*, **120***b* when the switches **154**, **158** are open. The controller **140** is connected to a driver circuit **170** which is used to transmit the physical address generated by the code generator **144** to the adapter pod **40***a* via the line **133**.

FIG. **12** illustrates a block diagram of the adapter pod **40***a* shown schematically in FIG. **1**. Referring to FIG. **12**, the adapter pod **40***a* has a controller **180** which is powered by a power supply **182** connected to the electrical power lines **120***a*, **120***b*. The controller **180** may transmit a check-in code on the line **133** via a driver **184**. The controller **180** receives network messages from the data bus **152** and transmits messages onto the data bus **152** via a transceiver **186**.

The controller **180** is connected to a memory **188** and to a device interface circuit **190**. The device interface circuit **190** has a plurality of data lines **192** and a plurality of electrical power lines **194** which are connected to the perfusion device **50***a* via the connector **84** (FIG. **7**). The controller **180** causes various types of data signals to be transmitted to the perfusion device **50***a* via the data lines **192**.

Depending on the type of perfusion device **50** to which an adapter pod **40** is connected, the signals on the data lines **192** might include, for example, digital or analog signals (e.g. 4–20 ma signals) relating to the control of the perfusion device **50**, such as a desired pump speed or mode of operation. The number of data lines **192** used depends on the particular perfusion device **50** to which the adapter pod **40** is connected.

The controller **180** also causes various types of electrical power to be transmitted to the perfusion device **50** via the power lines **194**. These types of power include, for example, +5 volt DC power or +24 volt DC power. If power of another voltage level is necessary, the power supply circuit **182** may comprise a DC/DC converter.

Configuration and Display of Perfusion Circuit

Prior to using the perfusion system **10** for a medical procedure, the operator connects the desired perfusion devices **50** to the main controller **20** by physically connecting the desired adapter pods **40** and/or network extenders **22** to the main controller **20**, as shown in FIG. **8**.

Prior to the commencement of a medical procedure, the perfusion system **10** is configured during a configuration process illustrated in FIG. **13**A, which is a flowchart of a configuration computer program routine **200** executed by the main controller **20**. Referring to FIG. **13**A, at step **202** the program generates a visual prompt to the operator to request whether a previous configuration file should be loaded from the memory **104** of the main controller **20**. A configuration file generally includes image data corresponding to an image of a perfusion circuit, which may include an outline of the patient, images of a plurality of fluid conduits connected to the patient, and images of the various perfusion devices **50** used in the system **10**. Each perfusion device **50** may be represented by a different image, depending upon the type of perfusion device. For example, pumps may be represented by a pump image, whereas a flow sensor may have a different image.

The configuration file may also include data relating to the perfusion devices **50**, such as the manufacturer and model number of the device, the desired operational mode of the device, numeric limits at which an alarm should be triggered, and identification of any associated perfusion device. Two perfusion devices may be "associated" if one device that is used to control a physical process, referred to herein as a control device, is to receive feedback from another perfusion device, referred to herein as a sensing device.

For example, referring to FIG. **1**, the pump **50***g* could be controlled based on feedback generated by either the level sensor **50***h* (which would generate a signal indicative of fluid level within a fluid reservoir) or the flow sensor **50***a*. In the former case, the pump **50***g* could be controlled to maintain a predetermined level of fluid within the reservoir, and in the latter case the pump **50***g* could be controlled to maintain a predetermined flow through the conduit. Any type of conventional feedback control could be used, such as proportional-integral (PI) or proportional-integral-derivative (PID) control. Where it is desired to control the pump **50***g* based on the output of the level sensor **50***h*, the association of the pump **50***g* with the level sensor **50***h* would be stored in the configuration file.

Referring to FIG. **13**A, if the operator requested the loading of a configuration file at step **202**, the program branches to step **204** where the operator is prompted to select one of those configuration files. If the operator did not want

to retrieve a previously stored configuration file, the program branches to step **206**, where the operator selects one of a predetermined number of types of perfusion circuit images. Each perfusion circuit image could correspond to the perfusion circuit that would be utilized for a different medical procedure. Two different types of perfusion circuit images are illustrated in FIGS. **14**A, **14**B described below.

At step **208**, either the perfusion circuit image corresponding to the configuration file selected at step **204** or the perfusion circuit image selected at step **206** is displayed on the display **114**. A pair of exemplary perfusion circuit images that may be displayed on the display **114** are illustrated in FIGS. **14**A and **14**B.

Referring to FIG. **14**A, an image **232** of a perfusion circuit corresponding to a left ventricle assist device (LVAD)) configuration is shown. The perfusion circuit image **232** includes a patient image **234**, an image **236** of a fluid conduit which removes blood from the left ventricle of the patient, an image **238** of a pump, an image **240** of a fluid conduit which returns blood to the aorta of the patient, an image **242** of a flow occluder, an image **244** of a temperature sensor, and a pair of images **246** of an air embolus sensor.

Referring to FIG. **14**B, an image **248** of a perfusion circuit corresponding to a bi-ventricular assist device (Bi-VAD) configuration is shown. The perfusion circuit image **248** includes all of the images shown in FIG. **14**A, as well as an image **250** of a second blood pump, an image **252** of a conduit which removes blood from right ventricle of the patient, and an image **254** of a conduit that returns blood to the pulmonary artery of the patient. Each of the perfusion circuit images illustrated in FIGS. **14**A, **14**B could be pre-stored in the memory **104** of the main controller **20**, in addition to other types of perfusion circuit images.

At step **210**, the operator may select one of a number of configuration options to change the configuration of the perfusion system **10**. If the operator selects the option of adding a perfusion device **50** as determined at step **212**, the program branches to step **214** where the operator is prompted to select a type of perfusion device **50**, such as a pump or a flow sensor, to add to the perfusion circuit image displayed on the display **114**.

At step **216**, the operator selects the position at which an image of the newly selected perfusion device **50** will be displayed. This position could be specified by the operator via an electronic mouse, and the displayed perfusion circuit image could include a number of possible connection points **256** (FIG. **14**A) at which the perfusion device **50** could be connected. The possible connection points **256** could be highlighted, such as by placing them in a bold color or making them blink on and off, so that the possible connection points **256** are readily apparent to the operator. After the operator selects the position, at step **218**, an image of the perfusion device is displayed in the perfusion circuit image at that position.

If the operator selected the option of configuring one of the perfusion devices as determined at step **220**, the program branches to step **222** where the current configuration of the perfusion device **50** is displayed next to the image of the device in the perfusion circuit. As noted above, the current configuration could include the mode of operation of the perfusion device, alarm limits for the device, any associated perfusion devices, etc. At step **224**, the operator may change or add to the current configuration.

If the operator selected the option of displaying data for the perfusion devices as determined at step **226**, the program branches to step **228** where it checks to determine whether there is data available to display. Such data could include, for example, the manufacturers and model numbers of the perfusion devices. If there is data available as determined at step **228**, the program branches to step **230** where the data is displayed next to the perfusion devices in the perfusion circuit.

Connecting Perfusion Devices

The main controller **20** may utilize a plug-in procedure to accommodate perfusion devices **50** that are subsequently connected to the perfusion system **10**. FIG. **13**B is a flowchart of a plug-in routine **260** performed by the main controller **20**. During the plug-in routine, the main controller **20** may operate in an automatic match mode in which it can match a previously entered device configuration with a perfusion device that is subsequently connected to the main controller **20**. For example, a operator may configure a centrifugal blood pump (not yet connected to the main controller **20**) to operate in a continuous mode to continuously pump a predetermined flow. When the blood pump is subsequently connected to the controller **20**, the controller **20** will then automatically match the previously stored pump configuration with the pump.

Referring to FIG. **13**B, at step **262**, if the main controller **20** is in the automatic match mode, the program branches to step **264** where it determines whether there is only one possible match between the perfusion device just connected and the previously stored device configurations. This would be the case where there is only one previously stored configuration for a pump and where the device that was just connected to the main controller **20** was a pump.

If there was only one possible match as determined at step **264**, the program branches to step **266** where it determines whether the position at which the device is to be displayed in the perfusion circuit image is known. This position could be included in the previously stored configuration for the device. If the position is not known, the program branches to step **268** where the operator is prompted to select a position, and then the program branches to step **270** where an image of the newly connected perfusion device is displayed in the perfusion circuit image. If the position of the device as determined at step **266** was known, the program skips step **268** and branches directly to step **270**.

If the main controller **20** was not in the automatic match mode, as determined at step **262**, or if there was more than one possible match, as determined at step **264**, the program branches to step **272**. If the newly connected device has already been configured, the program branches to step **274** where the operator is prompted to select the proper configuration from a plurality of prestored configurations. If the device is not already configured, the program branches to step **276** where the operator enters the desired configuration parameters for the device. The program then performs steps **268** and **270** described above.

Network Communications

The network controller **106** (FIG. **2**) in the main controller **20**, which may be a conventional network controller such as a CAN Version 2.0B, oversees the data flow on the network buses **30**, each of which includes the data bus **152** (which may be composed of two wires) on which digital data packets are transmitted and received. The data packets may have a conventional format composed of the following data fields: 1) a start-of-frame (SOF) field; 2) an arbitration field; 3) a control field; 4) a variable-length data field; 5) an error detection/correction field, such as a cyclic-redundancy-

check (CRC) field; 6) an acknowledgement (ACK) field; and 7) an end-of-frame (EOF) field.

The arbitration field, which may be a 29-bit field, is used to determine the priority of the data packets broadcast over the network bus **30**. The priority is based on the overall numeric value of the arbitration field of the data packets. In the event of a conflict in the transmission of two data packets, the data packet having the arbitration field with a lower numeric value takes priority. The arbitration fields, which contain a message identification (ID) code specifying the type of message, of a number of different data packet types that may be used are listed below.

Type	Message ID (MSB to LSB)			
A	00000	00000000	cccccccc	cccccccc
B	00000	00000001	cccccccc	cccccccc
C	00000	00000010	aaaaaaaa	ssssssss
D	00000	00000100	cccccccc	ssssssss
E	00001	cccccccc	cccccccc	dddddddd
F	00010	cccccccc	cccccccc	ssssssss
G	10000	ccacccccc	dddddddd	dddddddd
H	10001	cccccccc	ssssssss	ssssssss
I	11111	11111111	11111111	11111111

In the above table, the message types are listed from highest priority (at the top) to lowest priority (at the bottom). The type A message corresponds to a control message broadcast by the main controller **20** to all devices attached to the network data buses. The data fields "cccccccc cccccccc" are used to specify the type of message. The type B message corresponds to a message broadcast by the main controller **20** to the extender controllers **32**. The data fields "cccccccc cccccccc" are used to specify the type of message.

The type C message corresponds to an alarm or safety message, with the data field "aaaaaaaa" specifying an alarm type and the data field "ssssssss" specifying the logical address of the device which generated the alarm message. The type D message corresponds to a servo message generated by a sensing device, such as a flow sensor. The data field "cccccccc" specifies the type of sensed parameter, e.g. flow, and the data field "ssssssss" specifies the logical address of the sensor that generated the sensed parameter.

The type E message corresponds to a general message having a data field "cccccccc cccccccc" which specifies the type of message and a data field "dddddddd" which specifies the logical address of the intended destination of the message. The type F message corresponds to a general message having a data field "cccccccc cccccccc" which specifies the type of message and a data field "ssssssss" which specifies the logical address of the source of the message.

The type G message corresponds to a general message having a data field "cccccccc" which specifies the type of message and a data field "dddddddd dddddddd" which specifies the physical address of the intended destination of the message. The type H message corresponds to a general message having a data field "cccccccc" which specifies the type of message and a data field "ssssssss ssssssss" which specifies the physical address of the source of the message. The type I message (which is all logical "1"s) corresponds to a status request from the main controller **20** that is periodically broadcast to all devices connected to the network data buses.

Some of the message types described above are transmitted without any data fields. For example, the status request message from the main controller **20** would not have a data field. Other messages would include data fields. For example, the servo message (type D above) would include a data field which specified the numeric value of the sensed condition, such as a flow reading of 0.257 liters per minute.

The main controller **20**, the extender controllers **32**, and the adapter pods **40** may include conventional electronics for checking the accuracy of received messages via the CRC field, requesting retransmission of messages that were not accurately received, and for transmitting acknowledgement messages in response to the receipt of accurately received messages.

The messages described above may be transmitted or broadcast to all the devices connected to the network **30**. Each device, such as a pod **40** or an extender controller **32**, can discriminate by receiving only certain messages that are broadcast. For example, this discrimination could be accomplished by accessing a message-discrimination memory in the receiving device which stores the logical addresses of all the other devices in which the receiving device is interested.

For example, if the receiving device is the adapter pod **40***c* connected to the blood pump **50***c* which controls the flow of blood through a conduit based on receiving a feedback signal from the flow sensor **50***a*, the message-discrimination memory of the pod **40***c* would include the logical address of the flow sensor **50***a*, so that the pod **40***c* would receive any message generated by the pod **40***a* connected to the flow sensor **50***a*.

The message-discrimination memory would include logical address of the main controller **20**, and could include the logical addresses of a number of other pods **40**. Consequently, it should be noted that it is not necessary that messages broadcast over the network **30** include a specific destination address (although a destination address may be included).

The pods **40** and extender controllers **32** could also discriminate messages based on the type of message instead of the identity of the sender. For example, a pod **40** could receive all status-request messages and configuration messages (described below). The message identification codes for such messages could also be stored in the message-discrimination memory.

Before use of the perfusion system **10** for a medical procedure, and after all the perfusion devices **50** are configured as described above, data packets containing configuration messages are transmitted to all the pods **40** connected to the network **30**. The configuration messages include all the necessary configuration data described above. For example, for a blood pump, the configuration data would include the operational mode of the pump, the desired flow rate of the pump, etc. If any configuration messages which include device association data (e.g. the sensor which a blood pump should receive feedback from) were received by a pod **40**, the message-discrimination memory would be updated with the logical address of the associated device.

Connecting Pods to the Network

In order for them to communicate with the main controller **20** via the network data/power buses **30**, the adapter pods **40** must be granted permission to connect to the network **30**. This connection is initiated with a startup-request message transmitted to the main controller **20** by the adapter pod **40** for which the network connection is to be made. The startup-request message includes a first code identifying the type of perfusion device **50** connected to the pod **40** requesting to be connected and a second code identifying the physical address (specified by the code generator **144** of FIG. **11**) of the pod **40** requesting to be connected.

FIG. **13**C is a flowchart of a startup routine **280** that is performed by the main controller **20** in response to the receipt of a startup-request message from an adapter pod **40**. The startup routine **280** may be an interrupt service routine which is invoked in response to an interrupt generated upon the receipt of a startup-request message by the main controller **20**. Referring to FIG. **13**C, at step **282**, the startup message received by the main controller **20** is decoded to determine the type of the perfusion device **50** attached to the pod **40** requesting to be connected and to determine the physical address of the pod **40**.

At step **284**, the program determines whether full power should be granted to the requesting pod **40**. As described above, electrical power to run the perfusion devices **50** is provided to the pods **40** via the network **30** from a power supply **118** (FIG. **9**) in the main controller **20**. Since the power available from the power supply **118** may be limited, the main controller **20** may be programmed to allow only a certain number of perfusion devices **50** to be connected to the network **30**, or alternatively, to allow only certain numbers of specific types of perfusion devices **50** to be connected. For example, since control devices such blood pumps typically draw more power than sensing devices, the main controller **20** may be provided with an upper limit on the number of control devices that can be connected to the network **30**.

At step **284**, the decision whether to grant full power could be made by comparing the number of perfusion devices **50** already connected to the network **30** with the maximum number that can be connected to determine whether the connection of an additional device **50** will cause the maximum to be exceeded. Alternatively, if the device requesting connection is a control device, then the number of control devices already connected could be compared with the maximum number of control-type perfusion devices that can be connected. If it is determined that full power should not be granted, the program simply ends.

If it is determined that full power should be granted, steps **286–298** are performed to generate and transmit a startup granted message that will cause the pod **40** associated with the perfusion device **50** to be connected to the network **30**. In particular, at step **286**, a unique logical address is allocated to the newly connected pod **40**. For example, where the capacity of the network **30** is sixteen devices, the logical address may be a four-bit binary code. At step **288**, a startup-granted message which includes the logical address is encoded, and at step **290** the startup-granted message is transmitted over the network **30**.

At step **292**, if the pod **40** which requested startup is local to the main controller **20** (i.e. if it is one of the pods **40***g* or **40***h* directly connected to the main controller **20** without a network extender **22**), full power to the pod **40** is enabled via the local node controller (i.e. one of the node controllers **34***i*–**34***j* of FIG. **9**) connected to the perfusion device **50**. Referring to FIG. **11**, this is accomplished by sending an enable signal on the line **134**, which will cause the controller **140** to close the switches **150**, **154**, **158** so that full power is supplied on the power lines **120***a*, **120***b* and so that the adapter pod **40** is connected to the data bus **152**.

Referring to FIG. **13**C, if the perfusion device was not a local device as determined at step **292**, the program branches to step **296** where a connect message which includes the physical address of the node controller **34** associated with the pod **40** requesting startup is encoded, and then to step **298** where the connect message is transmitted over the network **30**. As described below, when the extender controllers **32** receive the connect message, they decode it to determine the physical address, and the extender controller **32** connected to the node controller **34** having that physical address (i.e. the node controller **34** associated with the requesting pod **40**) turns on full power by transmitting an enable signal on the line **134** connected to that node controller.

Status Requests

During operation of the perfusion system **10**, to ensure that all devices connected to the network **30** are property functioning and are receiving messages broadcast over the network **30**, the main controller **20** periodically transmits a status-request message to all extender controllers **32** and adapter pods **40** on the network **30**. Each extender controller **32** and adapter pod **40** must respond to the status request within a predetermined period of time. Any extender controller **32** or pod **40** that fails to respond to the status request within that time period is disconnected from the network **30**, and a corresponding alarm message is generated on the visual display **114** to warn the operator of such event.

FIG. **13**D is a flowchart of a status-request routine **300** periodically performed by the main controller **20**. Referring to FIG. **13**D, at step **302** a status-request message is encoded, and at step **304** the message is broadcast to all extender controllers **32** and adapter pods **40** connected to the network **30**. As described above, the status-request message may simply be all logical "1"s in the arbitration of the data packet. At step **306**, a predetermined time-out period within which all extender controllers **32** and pods **40** must respond to the status request message is started.

Upon receiving the status-request message, each extender controller **32** and adapter pod **40** encodes a status message with its logical address and its status, and then broadcasts the status message to the main controller **20** over the network **30**.

FIG. **13**E is a flowchart of a receive status routine **310** that is performed by the main controller **20** upon receipt of a status message transmitted to it in response to the status-request message previously transmitted by the routine **300**. Referring to FIG. **13**E, at step **312** the logical address of the responding extender controller **32** or adapter pod **40** is determined from the status message, and at step **314** the status of the device **32** or **40** is determined from the message. The status may be specified by a number of different binary status codes. At step **316**, if the status of the device **32** or **40** is okay, the program simply ends. However, if the status is not okay, the program branches to step **318** where it responds to a status condition identified by the status code. If the condition is relatively minor, the main controller **20** may simply generate a warning on the visual display **114** of the perfusion system **10**. If the condition is serious enough, the main controller **20** may disconnect the device **32** or **40** from the network **30**.

FIG. **13**F is a flowchart of a disconnect routine **330** that causes an extender controller **32** or an adapter pod **40** to be disconnected from the network **30**. The disconnect routine **330** is performed by the main controller **20** in response to either: 1) the failure of a device **32** or **40** to transmit a status message to the main controller **20** within the timeout period described above or 2) a serious malfunction of a device **32** or **40** as determined at step **318** of FIG. **13**E.

Referring to FIG. **13**F, at step **332**, if the device **32** or **40** to be disconnected is local to the main controller **20**, the program branches to step **334** where that device **32** or **40** is disconnected by the node controller **34***g*, **34***h*, **34***i*, or **34***j* in

the main controller **20** that is connected to that device **32** or **40**. Referring to FIG. **11**, the disconnection is accomplished by transmitting a disable signal on the line **134**, which will cause the controller **140** to open the switches **150**, **154**, **158** so that the data bus **152** and the power lines **120***a*, **120***b* are disconnected.

At step **332**, if the device to be disconnected is not local to the main controller **20**, the program branches to step **336** where a disconnect message which includes the physical address of the node controller **34** of the device **32** or **40** to be disconnected is encoded, and then to step **338** where the disconnect message is transmitted over the network **30**.

If the device to be disconnected is a pod **40** connected to an extender controller **32** via a node controller **34**, when that extender controller **32** receives the disconnect message, it decodes it to determine the physical address of the pod **40** to be disconnected, and the node controller **34** associated with that pod **40** disconnects the pod **40** by transmitting a disable signal on the line **134** connected to that node controller **34**.

Operator Commands Input to Main Controller

During operation of the perfusion system **10** during a medical procedure, the main controller **20** responds to various commands and other inputs entered by the operator of the system **10**. FIG. **13**G is a flowchart of a control command routine **350** which illustrates how the main controller **20** responds to those inputs. While FIG. **13**G discloses various possible operator inputs, it should be understood that the main controller **20** could respond to other or additional operator inputs.

Referring to FIG. **13**G, at step **352**, if the input entered by the operator was a control command, the program branches to step **354** where a control message corresponding to the control command is encoded in a data packet, and then to step **356** where the control message is broadcast over the network **30**. For example, the control message could be one of the following: 1) a new alarm limit for a particular sensing device; 2) a new mode of operation for a blood pump; 3) a new target flow value for a blood pump; 4) a new rate at which a particular sensing device should be read; 5) a pump start command; 6) a pump stop command; etc.

At step **358**, if the operator requests that a particular alarm be reset, the program branches to step **360** where a corresponding alarm-reset message, which includes the logical address of the device that generated the alarm, is encoded and to step **362** where the alarm-reset message is broadcast over the network **30**. At step **364**, if the operator requests that the perfusion system **10** be reset, the program branches to step **366** where a corresponding system reset message is encoded and to step **362** where the system reset message is broadcast over the network **30**.

Receipt of Network Messages by Main Controller

During operation, the main controller **20** receives messages of various types that are broadcast over the network **30**. FIG. **13**H is a flowchart of a receive routine **370** performed by the main controller **20** that illustrates actions taken by the main controller **20** in response to the receipt of various types of messages.

Referring to FIG. **13**H, at step **372**, if the received message corresponds to an event message, such as an alarm or other event, the program branches to step **374** where the visual display generated on the display device **114** is updated to advise the operator of that event, and the program branches to step **376** where the event is logged into an event log stored in the memory **104** of the main controller **20**.

At step **378**, if the received message corresponds to a data message, such as a message which includes the numeric value representing the output of a flow sensor, the program branches to step **380** where the visual display is updated, and the program branches to step **382** where the data and the device which generated the data are logged into a data log stored in the memory **104** of the main controller **20**.

At step **384**, if the received message is a status message, the program branches to step **386** where the status message is processed, as described above in connection with FIG. **13**E. At step **388**, the visual display is updated based on the status, and at step **390** the status is stored in a status log stored in memory. At step **392**, if the received message is a startup request, the program branches to step **394** where the startup request is processed, as described above in connection with FIG. **13**C, and at step **396**, the visual display is updated.

Operation of Extender Controllers

A basic function of the extender controllers **32** is to control the connection and disconnection of adapter pods **40** to the network **30**. FIG. **15**A is a flowchart of a startup routine **420** performed by the controller **130** of each extender controller **32**. Referring to FIG. **15**A, at step **422** the extender controller **32** performs a number of internal self-tests, such as tests of an internal RAM and an internal ROM. At step **424**, if the tests were successful, the program branches to step **426** where the connection of the extender controller **32** to the network bus **30** is tested by transmitting a message onto the network bus **30** and simultaneously receiving the message from the network bus **30** as it is transmitted to determine if the message was in fact transmitted.

At step **428**, if the data bus test was successful, the program branches to step **430** where the extender controller **32** starts to periodically transmit a check-in code to its parent node controller **34** via the line **133**. As described below, each device (either an adapter pod **40** or an extender controller **32**) must periodically transmit a check-in code to its parent node controller **34** to maintain its connection to the network **30**.

At step **432**, the extender controller **32** waits for its physical address to be transmitted to it from its parent node controller **34**. At step **434**, if not all of the tests performed at steps **422** and **426** were passed, an error message is broadcast over the network **30**. The error message includes the physical address of the extender controller **32** and a binary code which specifies which test(s) were not passed.

If all tests were passed, the program branches to step **438** where a startup-request message containing the physical address of the extender controller **32** is encoded and broadcast over the network **30**. At step **440**, the program waits until a startup-granted message is received from the main controller **20**, and then at step **442** the program waits until full power is granted to the extender controller **32** via the electrical power lines **120***a*, **120***b* of its parent node controller **34**. When full power is granted, the program branches to step **444** where the extender controller **32** measures the voltages on and the current provided by the electrical power lines **120***a*, **120***b* to make sure they are within specification. At step **446**, if the power measurements are not within specification, the program branches to step **436** where a message to that effect is broadcast to the main controller **20** over the network **30**.

FIG. **15**B is a flowchart of a connect routine **450** performed by an extender controller **32** when it receives a

connect message from the main controller **20**. Referring to FIG. **15**B, at step **452**, the connect message received from the main controller **20** is decoded to determine the physical address of the adapter pod **40** to be connected to the network **30**. At step **454**, the physical address is inspected to determine if the adapter pod **40** to be connected is local to the extender controller **32**, meaning that the adapter pod **40** is one of the three that are connected to the extender controller **32**. If the pod **40** is not local to the extender controller **32**, no further action is taken and the routine **450** ends. If the pod **40** is local to the extender controller **32**, the program branches to step **456** where an enable signal is transmitted via one of the lines **134** to the node controller **34** associated with the adapter pod **40** to be connected, which causes the adapter pod **40** to be connected to the network **30** in the manner described above.

When an extender controller **32** receives a disconnect message from the main controller **20**, a disconnect routine **460** shown in FIG. **15**C is performed by the extender controller **32**. Referring to FIG. **15**C, at step **462**, the disconnect message received from the main controller **20** is decoded to determine the physical address of the adapter pod **40** to be disconnected to the network **30**. At step **464**, the physical address is inspected to determine if the adapter pod **40** to be disconnected is local to the extender controller **32**. If the pod **40** is not local, no further action is taken. If the pod **40** is local, the program branches to step **466** where a disable signal is transmitted via one of the lines **134** to the node controller **34** associated with the adapter pod **40** to be disconnected, which causes the adapter pod **40** to be disconnected to the network **30**.

Operation of Node Controllers

The basic function of the node controllers **34** is to connect and disconnect the adapter pods **40** (if a node controller **34** is the parent of an adapter pod **40**) and the extender controllers **32** (if a node controller **34** is the parent of an extender controller **32**) from the network **30**. The connection or disconnection is performed pursuant to an enable or disable signal received either from the main controller **20** or from the extender controller **32** associated with the node controller **34**, as described above. In addition, each node controller **34** requires its associated device **32** or **40** to periodically check-in. If the device **32** or **40** fails to check in with a proper check-in code, the node controller **34** disconnects the device **32** or **40** from the network **30**.

FIG. **16**A is a flowchart of a node routine **470** performed by each of the node controllers **34**. The routine **470** is performed upon the receipt by the node controller **34** of a check-in code received from the associated device **32** or **40**. Referring to FIG. **16**A, at step **472**, if the code received from the device **32** or **40** is not valid, no further action is taken and the routine ends. The check-in code may be the physical address specified by the code generator **144** (FIG. **11**) of the node controller **34**. To determine whether the code is valid, the node controller **34** may compare the received code to determine whether it matches a predetermined code.

If the check-in code was valid, the program branches to step **474** where a time-out timer is restarted. The time-out timer tracks the predetermined period of time within which the device **32** or **40** must transmit a valid check-in code. At step **476**, the node controller **34** transmits the physical address generated by the code generator **144** to the pod **40**. At step **478**, the node controller **34** connects the device **32** or **40** to the data bus **152** (FIG. **11**) by sending a signal to the switch **150** which causes it to close (or remain closed if it was already closed).

At step **480**, if the enable signal is present on the line **134** connected to the node controller **34**, the node controller **34** supplies full power to the device **32** or **40** by sending signals to the switches **154**, **158** (FIG. **11**) to cause them to close (or remain closed if they were already closed).

If the enable signal was not present as determined at step **480**, the program branches to step **484**, where the device **32** or **40** is disconnected from the data bus **152** by opening the switch **150** and to step **484** where the device **32** or **40** is disconnected from the electrical power lines **120***a*, **120***b* by opening the switches **154**, **158**.

If the device **32** or **40** fails to transmit a valid check-in code to the node controller **34** within the time-out period, a time-out routine **490** shown in FIG. **16**B is performed by the node controller **34**. Referring to FIG. **16**B, at step **492** the device **32** or **40** is disconnected from the data bus **152** by opening the switch **150**, and at step **494** the device **32** or **40** is disconnected from the electrical power lines **120***a*, **120***b* by opening the switches **154**, **158**.

Operation of Adapter Pods

The adapter pods **40** perform a number of functions, including receiving configuration and control messages transmitted by the main controller **20**, receiving sensing messages containing numeric values of sensed conditions, such as flow, and/or transmitting sensing messages over the network **30**. These functions are described below.

FIG. **17**A is a flowchart of a startup routine **520** performed by the controller **180** of each adapter pod **40**. Referring to FIG. **17**A, at step **522** the adapter pod **40** performs a number of internal self-tests, such as tests of an internal RAM and an internal ROM. At step **524**, if the tests were successful, the program branches to step **526** where the connection of the pod **40** to the data bus **152** is tested by transmitting a message onto the data bus **152** and simultaneously receiving the message from the data bus **152** as it is transmitted to determine if the message was in fact transmitted.

At step **528**, if the data bus test was successful, the program branches to step **530** where the adapter pod **40** starts to periodically transmit a check-in code to its parent node controller **34** via the line **133**. At step **532**, the pod **40** waits for its physical address to be transmitted to it from its parent node controller **34**. At step **534**, if not all of the tests performed at steps **522** and **526** were passed, an error message is broadcast over the network **30**. The error message includes the physical address of the pod **40** and a binary code which specifies which test(s) were not passed.

If all tests were passed, the program branches to step **538** where a startup-request message containing the physical address of the adapter pod **40** is encoded and broadcast over the network **30**. At step **540**, the program waits until a startup-granted message is received from the main controller **20**, and then at step **542** the program waits until full power is granted to the adapter pod **40** via the electrical power lines **120***a*, **120***b* of its parent node controller **34**. When full power is granted, the program branches to step **544** where the pod **40** measures the voltages on and the current provided by the electrical power lines **120***a*, **120***b* to make sure they are within specification. At step **546**, if the power measurements are not within specification, the program branches to step **536** where a message to that effect is broadcast to the main controller **20** over the network **30**.

During operation, an adapter pod **40** may receive control or configuration messages from the main controller **20** over the network. FIG. **17**B is a flowchart of a receive routine **550** that is performed when the adapter pod **40** receives a

message. Referring to FIG. **17**B, at step **552** the message is decoded to determine the control command embedded in the message, and at step **554**, the pod **40** transmits a control signal (via one or more of the data lines **192** in FIG. **12**) to the perfusion device **50** connected to it.

During operation, an adapter pod **40** may receive an alarm signal from the perfusion device **50** via one of the data lines **192**. When such an alarm signal is received, an alarm routine **560** shown in FIG. **17**C is performed by the pod **40**. Referring to FIG. **17**C, at step **562** an alarm message is encoded with the logical address of the perfusion device **50** that generated the alarm and the type of alarm, and at step **564** the alarm message is broadcast over the network **30** to the main controller **20**.

During operation, each adapter pod **40** connected to a perfusion device **50**, such as a flow sensor, which generates a sensing signal periodically reads the numeric value of the sensing signal via one of the lines **152**. The time period between successive readings of the sensing signal may be specified during the configuration process as described above.

FIG. **17**D is a flowchart of a sensing routine **570** that is performed when it is time to read the value of the sensing signal. Referring to FIG. **17**D, at step **572** the sensing signal is read via one of the data lines **152**. At step **574**, the numeric value of the sensing signal is encoded in a message along with the logical address of the perfusion device **50** which generated the sensing signal. At step **576**, that message is then broadcast over the network **30** to all devices connected to the network **30**.

As described above, each adapter pod **40** connected to the network **30** may be provided with a message-discrimination circuit which is used to selectively receive messages from only a subset of the devices connected to the network **30**. When the sensing message is broadcast at step **576**, the only devices that receive it are the main controller **20** (which may receive all messages broadcast over the network **30**) and the particular perfusion device **50** which is being controlled based on the value of the sensing signal encoded in the sensing message.

It should be understood that the adapter pods may be provided with additional functionality not described above. Also, instead of having electrical power being distributed over the network from a single power source provided in the main controller **20**, electrical power could be distributed from a plurality of power sources, for example, from one power source provided in each of the network extenders.

Since numerous additional modifications and alternative embodiments of the invention will be apparent to those skilled in the art in view of the foregoing description, the above description is to be construed as illustrative only, and is for the purpose of teaching those skilled in the art the best mode of carrying out the invention. The details of the structure may be varied substantially without departing from the spirit of the invention, and the exclusive use of all modifications which come within the scope of the appended claims is reserved.

What is claimed is:

1. A medical perfusion system for use in connection with the medical treatment of a patient, comprising:

a first blood pump adapted to pump blood through a first conduit fluidly connected to the patient;

a second blood pump adapted to pump blood through a second conduit fluidly connected to the patient;

a first sensor for sensing a first condition relating to the pumping of blood through said first conduit, said first sensor generating a sensing signal relating to said first second condition;

a second sensor for sensing a condition relating to the pumping of blood through said second conduit, said second sensor generating a sensing signal relating to said second condition;

a data communications network for operatively interconnecting said blood pumps and said sensors, said data communications network having a plurality of network connectors, each of said network connectors having an identical connector configuration;

a first adapter pod having a common connector and a device connector, said common connector being adapted to be coupled to one of said network connectors and said device connector being adapted to be coupled to said first pump;

a second adapter pod having a common connector and a device connector, said common connector of said second adapter pod being adapted to be coupled to one of said network connectors and said device connector of said second adapter pod being adapted to be coupled to said second pump;

a third adapter pod having a common connector and a device connector, said common connector of said third adapter pod being adapted to be coupled to one of said network connectors and said device connector of said third adapter pod being adapted to be coupled to said first sensor;

a fourth adapter pod having a common connector and a device connector, said common connector of said fourth adapter pod being adapted to be coupled to one of said network connectors and said device connector of said fourth adapter pod being adapted to be coupled to said second sensor, said device connector of said fourth adapter pod having a different structure than said device connector of said first adapter pod;

means for transmitting messages in the form of digital data packets among said first and second blood pumps and said first and second sensors over said data communications network; and

a controller operatively coupled to said blood pumps and said sensors via said data communications network, said controller having an input device for accepting pump control commands relating to said first and second blood pumps from an operator.

2. A system as defined in claim **1** wherein said device connector of said fourth adapter pod has a first number of signal lines and wherein said common connector of said fourth adapter pod has a second number of signal lines different than said first number.

3. A system as defined in claim **1** wherein said means for transmitting messages comprises:

means for generating a message containing a control command for one of said pumps; and

means for generating a message containing data relating to one of said first and second conditions.

4. A system as defined in claim **1** wherein each of said adapter pods comprises means for generating a message in the form of a digital data packet.

5. A system as defined in claim **1** wherein said controller includes a plurality of network connectors and wherein said data communications network includes a network extender comprising:

a network connector adapted to be operatively coupled to one of said network connectors of said controller;

a plurality of extender connectors adapted to be connected to said common connectors of said adapter pods; and

a data bus electrically interconnecting said network connector of said network extender with each of said extender connectors.

6. A system as defined in claim **1** wherein said controller additionally comprises a network controller for controlling transmission of said messages over said data communications network.

7. A medical perfusion system for use in connection with the medical treatment of a patient, comprising:

a first type of perfusion device, said first type of perfusion device comprising a blood pump being adapted to pump blood through a fluid conduit connected to the patient;

a second type of perfusion device, said second type of perfusion device being adapted to sense a condition relating to the pumping of blood through said fluid conduit, said second type of perfusion device generating a sensing signal relating to said condition;

a data communications network for operatively interconnecting said first type of perfusion device and said second type of perfusion device, said data communications network having a plurality of network connectors, each of said network connectors having an identical connector configuration;

a first adapter pod having a common connector and a device connector, said common connector being adapted to be coupled to one of said network connectors and said device connector being adapted to be coupled to said blood pump;

a second adapter pod having a common connector and a device connector, said common connector of said second adapter pod being adapted to be coupled to one of said network connectors and said device connector of said second adapter pod being adapted to be coupled to said second type of perfusion device, said device connector of said second adapter pod having a different structure than said device connector of said first adapter pod;

means for transmitting messages in the form of digital data packets among said perfusion devices over said data communications network; and

a controller operatively coupled to said perfusion devices via said data communications network, said controller having an input device for accepting pump control commands relating to said blood pump from an operator.

8. A system as defined in claim **7** wherein said device connector of said first adapter pod has a first number of signal lines and wherein said common connector of said first adapter pod has a second number of signal lines different than said first number.

9. A system as defined in claim **7** wherein said means for transmitting messages comprises:

means for generating a message containing a control command for said pump; and

means for generating a message containing data relating to said condition.

10. A system as defined in claim **7** wherein each of said adapter pods comprises means for generating a message in the form of a digital data packet.

11. A system as defined in claim **7** wherein said controller includes a plurality of network connectors and wherein said data communications network includes a network extender comprising:

a network connector adapted to be operatively coupled to one of said network connectors of said controller;

a plurality of extender connectors adapted to be connected to said common connectors of said adapter pods; and

a data bus electrically interconnecting said network connector of said network extender with each of said extender connectors.

12. A system as defined in claim **7** wherein said controller additionally comprises a network controller for controlling transmission of said messages over said data communications network.

13. A medical perfusion system for use in connection with the medical treatment of a patient, comprising:

a first type of perfusion device, said first type of perfusion device comprising a blood pump being adapted to pump blood through a fluid conduit connected to the patient;

a second type of perfusion device, said second type of perfusion device being adapted to sense a condition relating to the pumping of blood through said fluid conduit, said second type of perfusion device generating a sensing signal relating to said condition;

a data communications network for operatively interconnecting said first type of perfusion device and said second type of perfusion device;

means for transmitting messages in the form of digital data packets among said perfusion devices over said data communications network; and

a controller operatively coupled to said perfusion devices via said data communications network, said controller having an input device for accepting pump control commands relating to said blood pump from an operator,

wherein said data communications network has a plurality of network connectors and a network extender comprising:

a network connector adapted to be operatively coupled to one of said network connectors of said controller;

a plurality of extender connectors; and

a data bus electrically interconnecting said network connector of said network extender with each of said extender connectors.

14. A system as defined in claim **13** wherein said means for transmitting messages comprises:

means for generating a message containing a control command for said pump; and

means for generating a message containing data relating to said condition.

15. A system as defined in claim **13** wherein said controller additionally comprises a network controller for controlling transmission of said messages over said data communications network.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.: 5,813,972

DATED: September 29, 1998

INVENTOR(S): Richard A. Nazarian, Dirk R. Smith, James R. Watts, Timothy J. Kriewall and Richard A. Griewski

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 18, line 3, before "condition" insert –second--.

Signed and Sealed this

Third Day of April, 2001

Attest:

NICHOLAS P. GODICI

Attesting Officer

Acting Director of the United States Patent and Trademark Office